CHESAPEAKE BAY WATER QUALITY MONITORING PROGRAM

LONG-TERM BENTHIC MONITORING AND ASSESSMENT COMPONENT LEVEL I COMPREHENSIVE REPORT

JULY 1984—DECEMBER 2005 (VOLUME 1)

Prepared for

Maryland Department of Natural Resources
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FOREWORD

This document, Chesapeake Bay Water Quality Monitoring Program: Long-Term Benthic Monitoring and Assessment Component, Level I Comprehensive Report (July 1984—December 2005), was prepared by Versar, Inc., at the request of Mr. Bruce Michael of the Maryland Department of Natural Resources under Contract # RAT7/06-201 between Versar, Inc. and Maryland DNR. The report assesses the status of Chesapeake Bay benthic communities in 2005 and evaluates their responses to changes in water quality.

ACKNOWLEDGEMENTS

We are grateful to the State of Maryland’s Environmental Trust Fund which partially funded this work. The benthic studies discussed in this report were conducted from the University of Maryland's research vessels and we appreciate the efforts of their captains and crew. We thank Nancy Mountford and Tim Morris of Cove Corporation who identified benthos in many of the samples from previous years and provided current taxonomic and autecological information. We also thank those at Versar whose efforts helped produce this report: the field crews who collected samples, including Martin Berlett, Craig Bruce, Donna Croson, Katherine Dillow, and Brenda Morgan; the laboratory technicians for processing samples, Dawn Hendrickson, Bobbi Mayer, Lay Nwe, Theresa Panzer, Diana Thaung, and Josh Vanderwagen; Suzanne Arcuri and Michael Winnel for taxonomic identifications; Allison Brindley for GIS support; Dr. Don Strebel for web-page development; and Sherian George and Gail Lucas for document production. Jodi Dew managed and analyzed the data.

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EXECUTIVE SUMMARY

Benthic macroinvertebrates have been an important component of the State of Maryland's Chesapeake Bay water quality monitoring program since the program's inception in 1984. Benthos integrate temporally variable environmental conditions and the effects of multiple types of environmental stress. They are sensitive indicators of environmental status. Information on the condition of the benthic community provides a direct measure of the effectiveness of management actions. The long-term benthic monitoring program contributes information to the Chesapeake Bay Health and Restoration reports, and to the water quality characterization and list of impaired waters under the Clean Water Act. This report is one in a series of annual reports that summarize data up to the current sampling year. Benthic community condition and trends in the Chesapeake Bay are assessed for 2005 and compared to results from previous years.

Sampling Design and Methods

Maryland's long-term benthic monitoring program currently contains two elements: a fixed site monitoring effort directed at identifying temporal trends and a probability-based sampling effort intended to assess the areal extent of degraded benthic community condition. Benthic community condition is assessed using the benthic index of biotic integrity (B-IBI), which evaluates the ecological condition of a sample by comparing values of key benthic community attributes to reference values expected under non-degraded conditions in similar habitat types. These reference values are the benthic community restoration goals for the Chesapeake Bay. Application of the B-IBI is limited to samples collected in summer, defined as July 15 through September 30.

Twenty-seven fixed sites are sampled twice a year, in May and in late August or September. Three replicate sediment samples for benthos are collected at each fixed site with gear used since 1984. These sites are part of a more extensive suite of sites that were sampled previously at various times and locations. The probability-based sampling design is stratified simple random. It was established in 1994. Twenty-five random sites are allocated annually to each of six strata in the Maryland portion of the Chesapeake Bay. A similar stratification scheme has been used by the Commonwealth of Virginia since 1996, permitting annual estimates for the entire Chesapeake Bay. The largest portion of the Chesapeake Bay, the mainstem, is divided into three strata, and five strata consist of the major tributaries (Patuxent, Potomac, Rappahannock, York, and James rivers). Two additional strata include the remaining smaller tributaries of the Maryland upper western shore and Maryland eastern shore. The strata sampled represent the entire tidal region of the Chesapeake Bay from freshwater to polyhaline zones. Probability sites are sampled once a year in late August or September. One sample is collected at each probability site using a Young grab with a surface area of 440 cm^2.

All samples are sieved on a 0.5-mm screen and preserved in the field. At each site, temperature, conductivity, salinity, dissolved oxygen concentration, and pH of the water column are measured at various depths, and silt-clay percent, total organic carbon, total inorganic carbon, and total nitrogen are measured from sediment samples processed in the laboratory.

Trends in Fixed Site Benthic Condition

Statistically significant B-IBI trends ($p<0.1$) were detected at 8 of the 27 sites currently monitored. Trends in benthic community condition declined at 3 sites (significantly decreasing B-IBI trend) and improved at 5 sites, as in 2004. Trends detected through 2004 were still present in 2005 at 7 sites. One trend that just emerged in 2004 disappeared with the addition of the 2005 data (Baltimore Harbor Sta. 23), and one trend that disappeared in 2004 was again significant in 2005 (Elk River Sta. 29).

Sites with improving B-IBI trends were located in the main stem of the Bay (Sta. 15 and 26), Elk River (Sta. 29), Choptank River (Sta. 64), and Potomac River at St. Clements Island (Sta. 51). Sites with degrading B-IBI trends were located in the Severn River (Sta. 204), Patuxent River at Holland Cliff (Sta. 77), and Nanticoke River (Sta. 62). Many of the trend sites showed reduced B-IBI scores in 2005 relative to the previous year. Lower B-IBI scores were obtained at locations prone to hypoxia such as at trend sites in Baltimore Harbor, Back River, Severn River, and lower Patuxent and Potomac rivers. None of the trend sites in the eastern shore tributaries of Maryland showed declines in the B-IBI in 2005.

Benthic organisms respond to long-term patterns in water quality parameters, such as dissolved oxygen concentrations, chlorophyll a, total nitrogen, and sediment loadings, in addition to natural fluctuations in salinity. Improving trends are likely to reflect undergoing basin-wide changes resulting from management actions. Degrading trends reflect the cumulative impacts of pollution loadings in regions with significant problems that are not yet responding to pollution abatement.

Baywide Benthic Community Condition

The area of Chesapeake Bay estimated to fail the restoration goals increased substantially from 47% in 2004 to 59% in 2005, one of the largest estimates of degraded benthic condition since baywide monitoring began in 1996. The higher estimates for 2005 were associated with high spring flows, which were responsible for high nutrient and sediment runoff leading to widespread hypoxia. Over the past decade, benthic community condition has varied with changes in hydrology (dry versus wet years) and year-to-year fluctuations in dissolved oxygen concentrations. However, benthic community degradation in Chesapeake Bay continues to be large in any given year. In the Maryland portion of the Bay, 65% of the tidal waters failed the Chesapeake Bay benthic community restoration goals in 2005, up from 52% in 2004. The extent of degradation in 2005 was similar to that of 2003, another wet year.

Forty percent (4,664 Km^2) of the Chesapeake Bay bottom in 2005 was severely degraded, the largest percentage since 1996. Forty-four percent (2,771 Km^2) of the Maryland portion was severely degraded. No obvious trends in the percentage of area with marginal, moderate, or severely degraded benthic condition were observed over the time series. An unusually large proportion of the random benthic sites was azoic (no macrofauna), pointing to severe hypoxia or anoxia during the summer months. With the exception of the James River, the major tributaries (Potomac, Patuxent, Rappahannock, and York rivers) and the Maryland mainstem were in the poorest condition. The upper Bay maistem was in best condition. The upper Bay mainstem above the Chester River is not generally influenced by hypoxia.

There is good agreement between the status and trends for water quality parameters and the benthic community condition. Over the period 1996-2005, high percentages of severely degraded sites failing the restoration goals due to insufficient abundance or biomass occurred in the Potomac River, Patuxent River, and the mainstem of the Chesapeake Bay. Sites with high incidence of failure due to excess abundance were most frequently located in the Maryland eastern shore tributaries, upper Bay mainstem, the James River, and the York River. Severely degraded and depauperate benthic communities are symptomatic of prolonged oxygen stress while excess abundance and biomass are symptomatic of eutrophic conditions in the absence of low dissolved oxygen stress. Low dissolved oxygen events are common and severe in the Potomac River and the Maryland mainstem. The Patuxent River experiences annual events of variable intensity. Maryland eastern tributaries have high agricultural land use, high nutrient input, and high chlorophyll values but low frequencies of low dissolved oxygen events. Baywide restoration goal failure due to severely degraded benthic fauna was more common than failure due to excess abundance or biomass of benthic organisms.

Despite substantial restoration efforts, significant changes in benthic condition that would indicate widespread improvements in abundance, diversity, or biomass of organisms, were not observed. Many of these bottom-dwelling organisms are the base for fisheries species and wintering sea-ducks (on-going study presented in this report). Even if the effect of hydrology (dry versus wet years) is factor out, the residual degradation is still large for any given year. It will probably take sustained management efforts over an extended period of time to bring back a more balanced community of benthic organisms to Chesapeake Bay.

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1.0 INTRODUCTION

1.1 BACKGROUND

Monitoring is a necessary part of environmental management because it provides the means for assessing the effectiveness of previous management actions and the information necessary to focus future actions (NRC 1990). Towards these ends, the State of Maryland has maintained an ecological monitoring program for Chesapeake Bay since 1984. The goals of the program are to:

- quantify the types and extent of water quality problems (i.e., characterize the "state-of-the-bay");

- determine the response of key water quality measures to pollution abatement and resource management actions;

- identify processes and mechanisms controlling the bay's water quality;

- define linkages between water quality and living resources;

- contribute information to the Chesapeake Bay Health and Restoration reports; and

- contribute information to the Water Quality Characterization Report (305b report) and the List of Impaired Waters (303d list).

The program includes elements to measure water quality, sediment quality, phytoplankton, and benthic macroinvertebrates (i.e., those invertebrates retained on a 0.5-mm mesh sieve). The monitoring program includes assessments of biota because the condition of biological indicators integrates temporally variable environmental conditions and the effects of multiple types of environmental stress. In addition, most environmental regulations and contaminant control measures are designed to protect biological resources; therefore, information about the condition of biological resources provides a direct measure of the effectiveness of management actions.

The Maryland program uses benthic macroinvertebrates as biological indicators because they are reliable and sensitive indicators of habitat quality in aquatic environments. Most benthic organisms have limited mobility and cannot avoid changes in environmental conditions (Gray 1979). Benthos live in bottom sediments, where exposure to contaminants and oxygen stress are most frequent. Benthic assemblages include diverse taxa representing a variety of sizes, modes of reproduction, feeding guilds, life history characteristics, and physiological tolerances to environmental conditions; therefore, they respond to and integrate natural and anthropogenic changes in environmental conditions in a variety of ways (Pearson and Rosenberg 1978; Warwick 1986; Dauer 1993; Wilson and Jeffrey 1994).

Benthic organisms are also important secondary producers, providing key linkages between primary producers and higher trophic levels (Virnstein 1977; Holland et al. 1980, 1989; Baird and Ulanowicz 1989; Diaz and Schaffner 1990). Benthic invertebrates are among the most important components of estuarine ecosystems and may represent the largest standing stock of organic carbon in estuaries (Frithsen 1989). Many benthic organisms, such as clams, are economically important. Others, such as polychaete annelids and small crustaceans, contribute significantly to the diets of economically important bottom feeding juvenile and adult fishes, such as spot and croaker (Homer and Boynton 1978; Homer et al. 1980).

The Chesapeake Bay Program's decision to adopt Benthic Community Restoration Goals (Ranasinghe et al. 1994a updated by Weisberg et al. 1997) enhanced use of benthic macroinvertebrates as a monitoring tool. Based largely on data collected as part of Maryland's monitoring effort, these goals describe the characteristics of benthic assemblages expected at sites exposed to little environmental stress. The Restoration Goals provide a quantitative benchmark against which to measure the health of sampled assemblages and ultimately the Chesapeake Bay. Submerged aquatic vegetation (Dennison et al. 1993) and benthic macroinvertebrates are the only biological communities for which such quantitative goals have been established in Chesapeake Bay. Restoration goals for phytoplankton and zooplankton are under development.

A variety of anthropogenic stresses affect benthic macroinvertebrate communities in Chesapeake Bay. These include toxic contamination, organic enrichment, and low dissolved oxygen. While toxic contamination is generally restricted to urban and industrial areas typically associated with ports, low dissolved oxygen (hypoxia) is the more widespread problem, encompassing an area of about 600 million m^2 mainly along the deep mainstem of the bay and at the mouth of the major Chesapeake Bay tributaries (Flemer et al. 1983). Organic enrichment, associated with phytoplankton growth and decay, is also a major problem in some regions of the Bay.

A variety of factors contribute to the development and spatial variation of hypoxia in the Chesapeake Bay. Freshwater inflow, salinity, temperature, wind stress, and tidal circulation are primary factors in the development of hypoxia (Holland et al. 1987; Tuttle et al. 1987; Boicourt 1992). The development of vertical salinity gradients during the spring freshwater run off leads to water column density stratification. The establishment of a pycnocline, in association with periods of calm and warm weather, restricts water exchange between the surface and the bottom layers of the estuary, where oxygen consumption is large. This process is especially manifested along the Maryland mid-bay and Potomac River deep troughs. The formation or the disruption of the pycnocline is probably the most important process determining the intensity and extent of hypoxia (Seliger et al. 1985; Boicourt 1992), albeit not the only one. Biological processes contribute significantly to deep water oxygen depletion in Chesapeake Bay (Officer et al.

1984). Benthic metabolic rates increase during spring and early summer, leading to an increase of the rate of oxygen consumption in bottom waters. This depends in part on the amount of organic carbon available for the benthos, which is derived to a large extent from seasonal phytoplankton blooms (Officer et al. 1984). Anthropogenic nutrient inputs to the Chesapeake Bay further stimulate phytoplankton growth, which results in increased deposition of organic matter to the sediments and a concomitant increase in chemical and biological oxygen demand (Malone 1987). Winter to spring accumulation of phytoplankton biomass has been linked to depletion of bottom water oxygen in Chesapeake Bay (Malone et al. 1988; Boynton and Kemp 2000).

The effects of hypoxia on benthic organisms vary as a function of the severity, spatial extent, and duration of the low dissolved oxygen event. Oxygen concentrations down to about 2 mg l^{-1} do not appear to significantly affect benthic organisms, although incipient community effects have been measured at 3 mg l^{-1} (Diaz and Rosenberg 1995; Ritter and Montagna 1999). Hypoxia brings about structural and organizational changes in the community, and may lead to hypoxia resistant communities. With an increase in the frequency of hypoxic events, benthic populations become dominated by fewer and short-lived species, and their overall productivity is decreased (Diaz and Rosenberg 1995). Major reductions in species number and abundance in the Chesapeake Bay have been attributed to hypoxia (Llansó 1992). These reductions become larger both spatially and temporally as the severity and duration of hypoxic events increase. As hypoxia becomes persistent, mass mortality of benthic organisms often occurs with almost complete elimination of the macrofauna.

Hypoxia has also major impacts on the survival and behavior of a variety of benthic organisms and their predators (Diaz and Rosenberg 1995). Many infaunal species respond to low oxygen by migrating toward the sediment surface, thus potentially increasing their availability to demersal predators. On the other hand, reduction or elimination of the benthos following severe hypoxic or anoxic (no oxygen) events may result in a reduction of food for demersal fish species and crabs. Therefore, the structural changes and species replacements that occur in communities affected by hypoxia may alter the food supply of important ecological and economical fish species in Chesapeake Bay. Given that dissolved oxygen and nutrient inputs are critical factors in the health of the resources of the Chesapeake Bay region, monitoring that evaluates benthic community condition and tracks changes over time helps Chesapeake Bay managers assess the effectiveness of nutrient reduction efforts and the status of the biological resources of one of the largest and most productive estuaries in the nation.

1.2 OBJECTIVES OF THIS REPORT

This report is part of a series of Level I Comprehensive reports produced annually by the Long-Term Benthic Monitoring and Assessment Component (LTB) of the Maryland Chesapeake Bay Water Quality Monitoring Program. Level I reports summarize data from the latest sampling year and provide a limited examination of how conditions in the latest year differ from conditions in previous years of the study, as well as how data from this year contribute to describing trends in the Bay's condition.

The report reflects the maturity of the current program's focus and design. Approaches introduced when the new program design was implemented in 1995 continue to be extended, developed, and better defined. The level of detail in which changes are examined at the fixed stations sampled for trend analysis continues to increase. For example, we report on how species contribute to changes in condition and discuss results in relation to changes in water quality. The Benthic Index of Biotic Integrity (B-IBI) is applied to each sampling site, from tidal freshwater to polyhaline habitats, and thus provides a uniform measure of ecological condition across the estuarine gradient. In describing baywide benthic community condition, estimates of degraded condition are presented for at least eight years for all subregions of the Bay, and community measures that contribute to Restoration Goal failure are used to diagnose the causes of failure.

The continued presentation of estimates of Bay area meeting the Chesapeake Bay Program's Benthic Community Restoration Goals, rather than Maryland estimates only, reflects improved coordination and unification of objectives among the Maryland and Virginia benthic monitoring programs. The sampling design and methods in both states are compatible and complementary.

In addition to the improvements in technical content, we have enhanced electronic production and transmittal of data. This report is produced in Adobe Acrobat format to facilitate distribution across the internet. Data and program information are available to the research community and the general public through the Chesapeake Bay Benthic Monitoring Program Home Page on the World-Wide-Web at http://www.baybenthos.versar.com. Expansion of the website continues, with new program information, data, and documents being added every year. The 2005 data, as well as the data from previous years, can be downloaded from this website. The Benthic Monitoring Program Home Page represents the culmination of collaborative efforts between Versar, Maryland DNR, and the Chesapeake Information Management System (CIMS). The activities that Versar undertakes as a partner of CIMS were recorded in a Memorandum of Agreement signed October 28, 1999.

1.3 ORGANIZATION OF REPORT

This report has two volumes. Volume 1 is organized into four major sections and three appendices. Section 1 is this introduction. Section 2 presents the field, laboratory, and data analysis methods used to collect, process, and evaluate the LTB samples. Section 3 presents the results of analyses conducted for 2005, and consists of two assessments: an assessment of trends in benthic community condition at sites sampled annually by LTB in the Maryland Chesapeake Bay, and an assessment of the area of the Bay that meets the Chesapeake Bay Benthic Community Restoration Goals. Section 4 discusses the results and evaluates status and trends relative to recent changes in water quality. Section 5 is the literature cited in the report. Appendix A amplifies information presented in Table 3-2 by providing p-values and rates of change for the 1985-2005 fixed site trend analysis. Finally, Appendices B and C present the B-IBI values for the 2005 fixed and random sampling components, respectively. Volume 2 consists of the benthic, sedimentary, and hydrographic data appendices.

2.0 METHODS

2.1 SAMPLING DESIGN

The LTB sampling program contains two primary elements: a fixed site monitoring effort directed at identifying trends in benthic condition and a probability-based sampling effort intended to estimate the area of the Maryland Chesapeake Bay with benthic communities meeting the Chesapeake Bay Program's benthic community restoration goals (Ranasinghe et al. 1994a, updated by Weisberg et al. 1997; Alden et al. 2002). The sampling design for each of these elements is described below.

2.1.1 Fixed Site Sampling

The fixed site element of the program involves sampling at 27 sites, 23 of which have been sampled since the program's inception in 1984, 2 since 1989, and 2 since 1995 (Figure 2-1). Sites are defined by geography (within 1 km from a fixed location), and by specific depth and substrate criteria (Table 2-1).

The 2005 fixed site sampling continues trend measurements, which began with the program's initiation in 1984. In the first five years of the program, from July 1984 to June 1989, 70 fixed stations were sampled 8 to 10 times per year. On each visit, three benthic samples were collected at each site and processed. Locations of the 70 fixed sites are shown in Figure 2-2.

In the second five years of the program, from July 1989 to June 1994, fixed site sampling was continued at 29 sites and a stratified random sampling element was added. Samples were collected at random from approximately 25 km^2 small areas surrounding these sites (Figure 2-3) to assess the representativeness of the fixed locations. Sites 06, 47, 62, and 77, which are part of the current design, were not sampled during this five-year period. Stratum boundaries were delineated on the basis of environmental factors that are important in controlling benthic community distributions: salinity regime, sediment type, and bottom depth (Holland et al. 1989). In addition, four new areas were established in regions of the Bay targeted for management actions to abate pollution: the Patuxent River, Choptank River, and two areas in Baltimore Harbor. Each area was sampled four to six times each year.

From July 1994 to the present, three replicate samples were collected in spring and summer at most of the current suite of 27 sites (Stations 203 and 204 were added in 1995, Table 2-1, Figure 2-1). This sampling regime was selected as being most cost effective after analysis of the first 10 years of data jointly with the Virginia Benthic Monitoring Program (Alden et al. 1997).

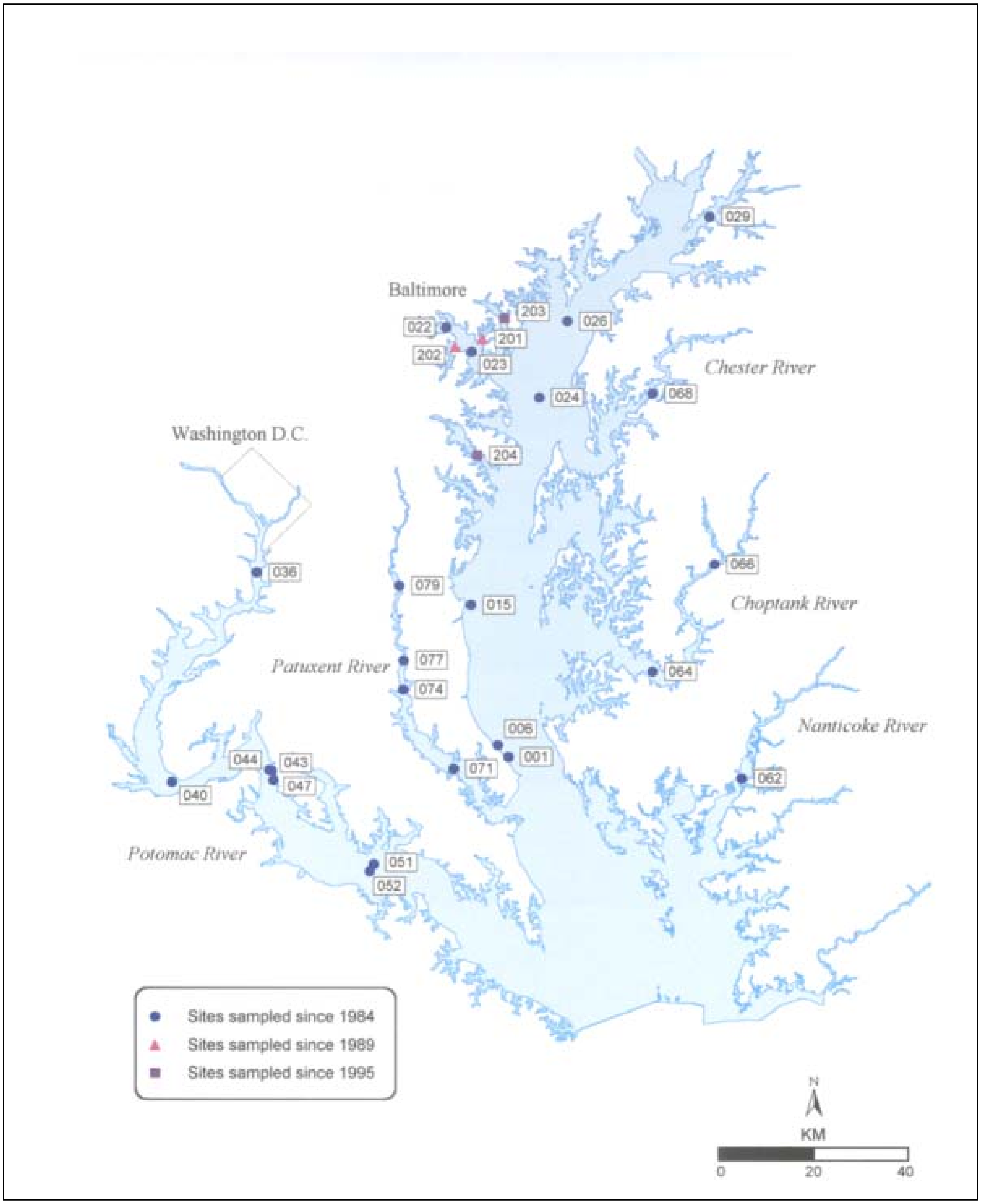

Figure 2-1. Fixed sites sampled in 2005

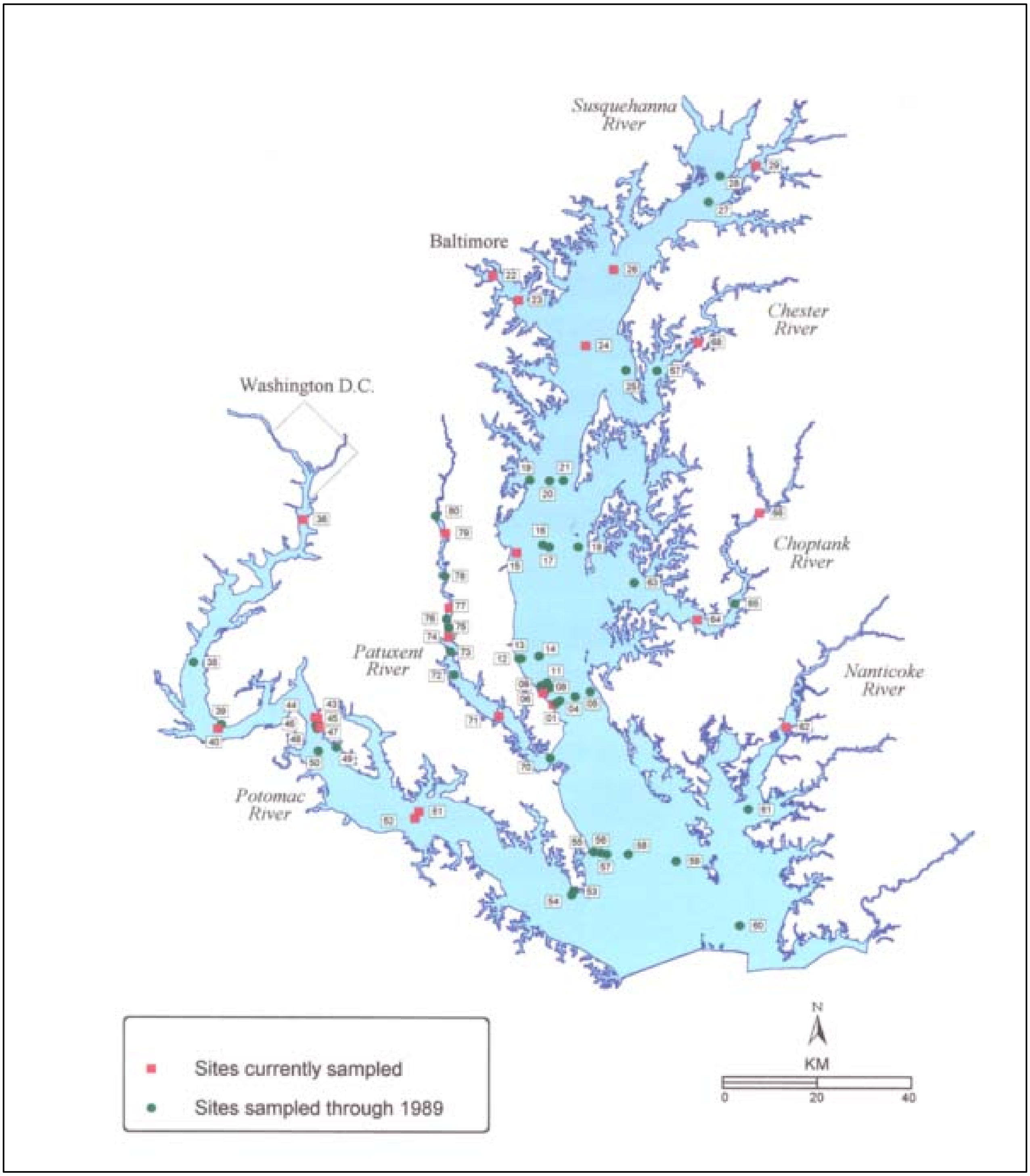

Figure 2-2. Fixed sites sampled from 1984 to 1989; some of these sites are part of the current design

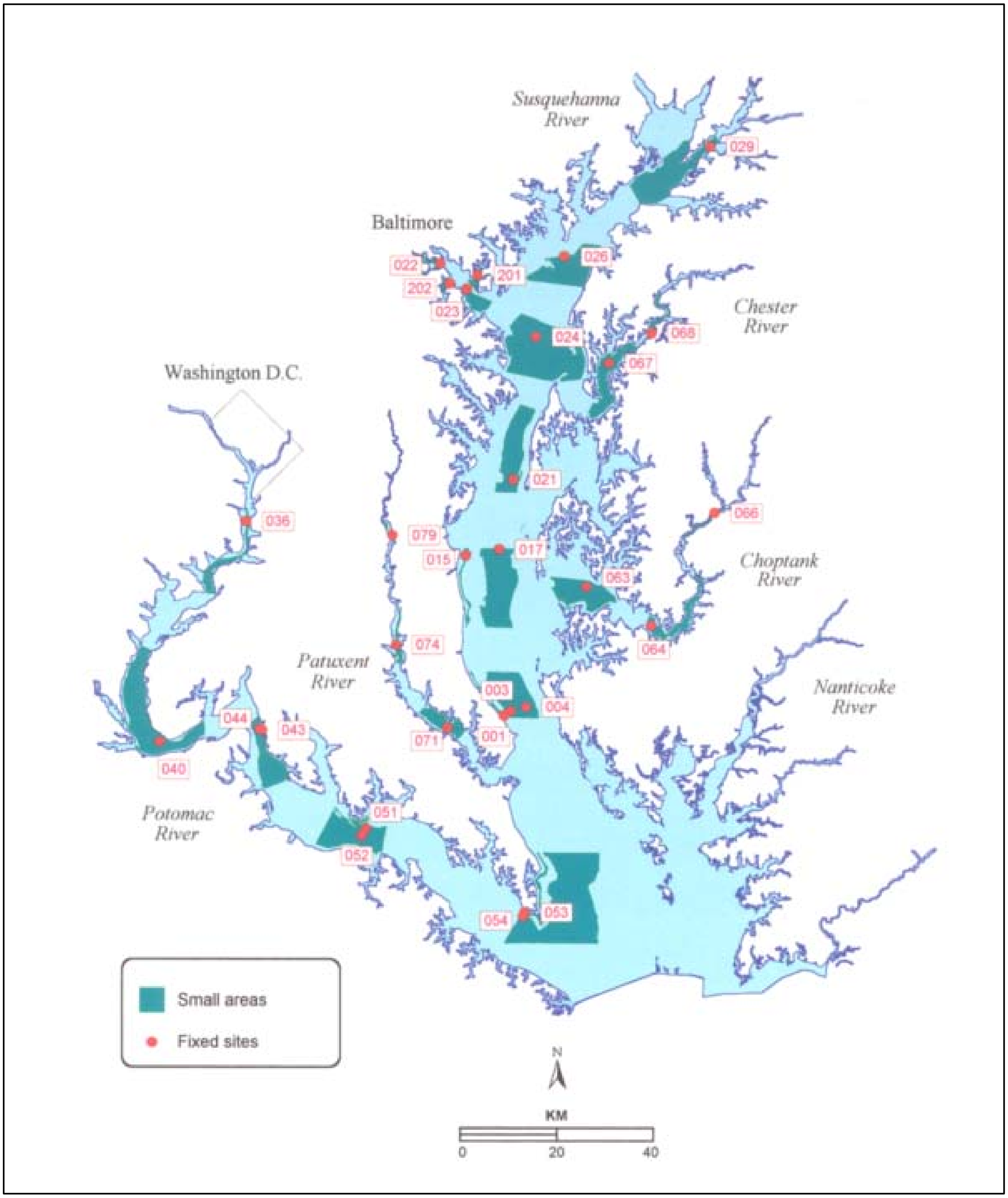

Figure 2-3. Small areas and fixed sites sampled from 1989 to 1994

Table 2-1. Location, habitat type (Table 5, Weisberg et al. 1997), sampling gear, and habitat criteria for fixed sites

Stratum	Sub-Estuary	Habitat	Station	Latitude (NAD 83)	Longitude (NAD 83)	Sampling Gear	Habitat Criteria		
							Depth (m)	Siltclay (%)	Distance (km)
Potomac River	Potomac River	Tidal Freshwater	036	38.769781	77.037531	WildCo Box Corer	< =5	> =40	1.0
		Oligohaline	040	38.357458	77.230534	WildCo Box Corer	6.5-10	> =80	1.0
		Low Mesohaline	043	38.384125	76.989028	Modified Box Corer	< =5	< =30	1.0
		Low Mesohaline	047	38.365125	76.984695	Modified Box Corer	< =5	< =30	0.5
		Low Mesohaline	044	38.385625	76.995695	WildCo Box Corer	11-17	> =75	1.0
		High Mesohaline Sand	051	38.205462	76.738020	Modified Box Corer	< =5	< =20	1.0
		High Mesohaline Mud	052	38.192297	76.747687	WildCo Box Corer	9-13	> =60	1.0
Patuxent River	Patuxent River	Tidal Freshwater	079	38.750448	76.689020	WildCo Box Corer	< =6	> =50	1.0
		Low Mesohaline	077	38.604452	76.675017	WildCo Box Corer	< =5	> =50	1.0
		Low Mesohaline	074	38.547288	76.674851	WildCo Box Corer	< =5	> =50	0.5
		High Mesohaline Mud	071	38.395124	76.548844	WildCo Box Corer	12-18	> =70	1.0

Table 2-1. (Continued)

Stratum	Sub-Estuary	Habitat	Station	Latitude (NAD 83)	Longitude (NAD 83)	Sampling Gear	Habitat Criteria		
							Depth (m)	Siltclay (%)	Distance (km)
Upper Western Tributaries	Patapsco River	Low Mesohaline	023	39.208275	76.523352	WildCo Box Corer	4-7	>=50	1.0
	Middle Branch	Low Mesohaline	022	39.254940	76.587354	WildCo Box Corer	2-6	>=40	1.0
	Bear Creek	Low Mesohaline	201	39.234275	76.497184	WildCo Box Corer	2-4.5	>=70	1.0
	Curtis Bay	Low Mesohaline	202	39.217940	76.563853	WildCo Box Corer	5-8	>=60	1.0
	Back River	Oligohaline	203	39.275107	76.446015	Young-Grab	1.5-2.5	>=80	1.0
	Severn River	High Mesohaline Mud	204	39.006778	76.504683	Young-Grab	5-7.5	>=50	1.0
Eastern Tributaries	Chester River	Low Mesohaline	068	39.132941	76.078679	WildCo Box Corer	4-8	>=70	1.0
	Choptank River	Oligohaline	066	38.801447	75.921825	WildCo Box Corer	<=5	>=60	1.0
		High Mesohaline Mud	064	38.590464	76069340	WildCo Box Corer	7-11	>=70	1.0
	Nanticoke River	Low Mesohaline	062	38.383952	75.849988	Petite Ponar Grab	5-8	>=75	1.0

Table 2-1. (Continued)

Stratum	Sub-Estuary	Habitat	Station	Latitude (NAD 83)	Longitude (NAD 83)	Sampling Gear	Habitat Criteria		
							Depth (m)	Siltclay (%)	Distance (km)
Upper Bay	Elk River	Oligohaline	029	39.479615	75.944499	WildCo Box Corer	3-7	>=40	1.0
	Mainstem	Low Mesohaline	026	39.271441	76.290011	WildCo Box Corer	2-5	>=70	1.0
		High Mesohaline Mud	024	39.122110	76.355346	WildCo Box Corer	5-8	>=80	1.0
Mid Bay	Mainstem	High Mesohaline Sand	015	38.715118	76.513677	Modified Box Corer	<=5	<=10	1.0
		High Mesohaline Sand	001	38.419956	76.416672	Modified Box Corer	<=5	<=20	1.0
		High Mesohaline Sand	006	38.442456	76.443006	Modified Box Corer	<=5	<=20	0.5

2.1.2 Probability-based Sampling

The second sampling element, which was instituted in 1994, was probability-based summer sampling designed to estimate the area of the Maryland Chesapeake Bay and its tributaries that meet the Chesapeake Bay benthic community restoration goals (Ranasinghe et al. 1994a, updated by Weisberg et al. 1997; Alden et al. 2002). Different probability sample allocation strategies were used in 1994 than in later years. In 1994, the design was intended to estimate impaired area for the Maryland Bay and one sub-region, while in later years the design targeted five additional sub-regions as well.

The 1994 sample allocation scheme was designed to produce estimates for the Maryland Bay and the Potomac River. The Maryland Bay was divided into three strata with samples allocated unequally among them (Table 2-2); sampling intensity in the Potomac was increased to permit estimation of degraded area with adequate confidence, while mainstem and other tributary and embayment samples were allocated in proportion to their area.

Table 2-2. Allocation of probability-based baywide samples, 1994

Stratum	Area		Number of Samples
	km^2	%	
Maryland Mainstem (including Tangier and Pocomoke Sounds)	3,611	55.5	27
Potomac River	1,850	28.4	28
Other tributaries and embayments	1,050	16.1	11

In subsequent years, the stratification scheme was designed to produce an annual estimate for the Maryland Bay and six subdivisions. Samples were allocated equally among strata (Figure 2-4, Table 2-3). According to this allocation, a fresh new set of sampling sites were selected each year. Figure 2-5 shows the locations of the probability-based Maryland sampling sites for 2005. Regions of the Maryland mainstem deeper than 12 m were not included in sampling strata because these areas are subjected to summer anoxia and have consistently been found to be azoic.

A similar stratification scheme has been used by the Commonwealth of Virginia since 1996, permitting annual estimates for the extent of area meeting the benthic community restoration goals for the entire Chesapeake Bay (Table 2-3, Figure 2-6). These samples were collected and processed, and the data analyzed by the Virginia Chesapeake Bay Benthic Monitoring Program.

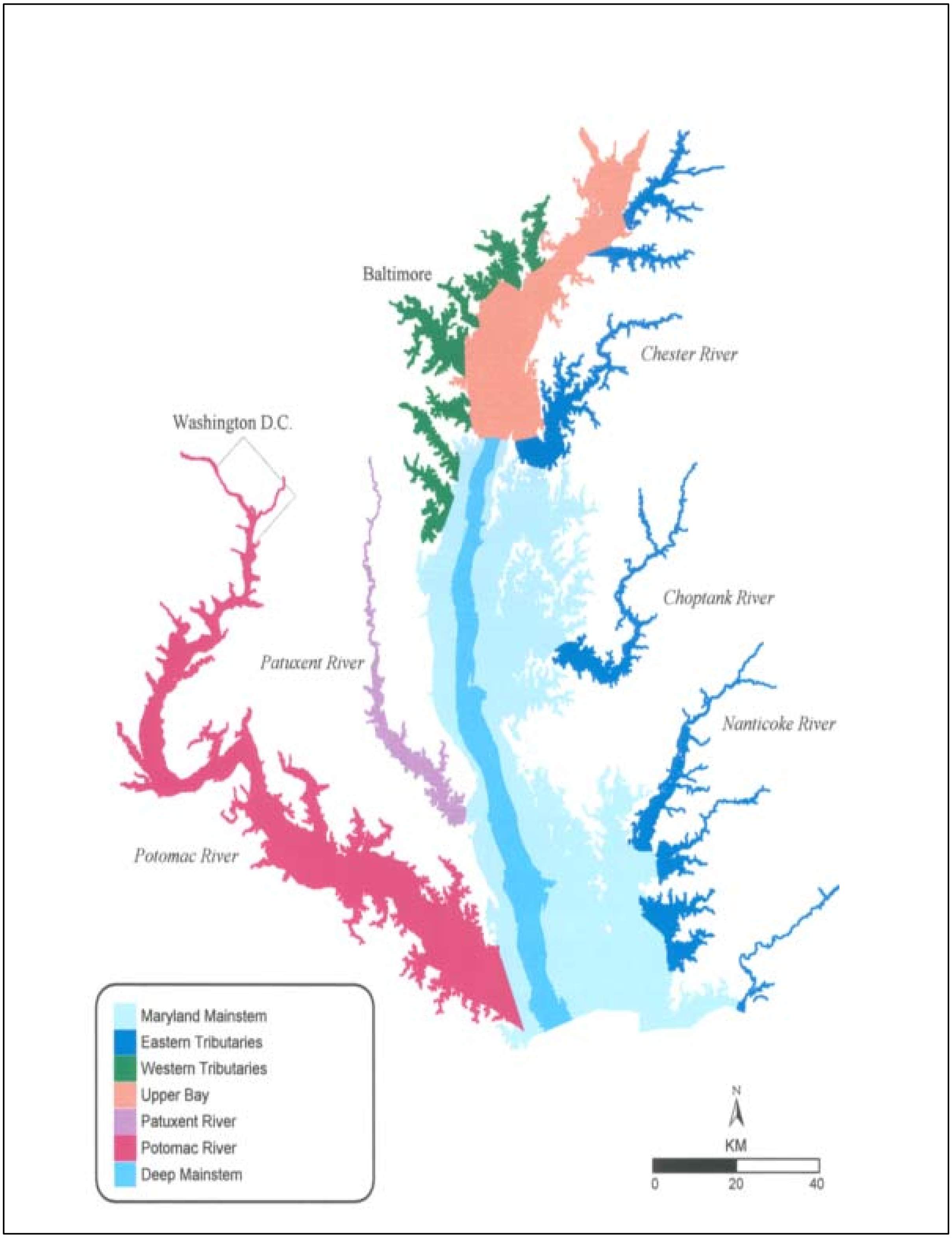

Figure 2-4. Maryland baywide sampling strata in and after 1995

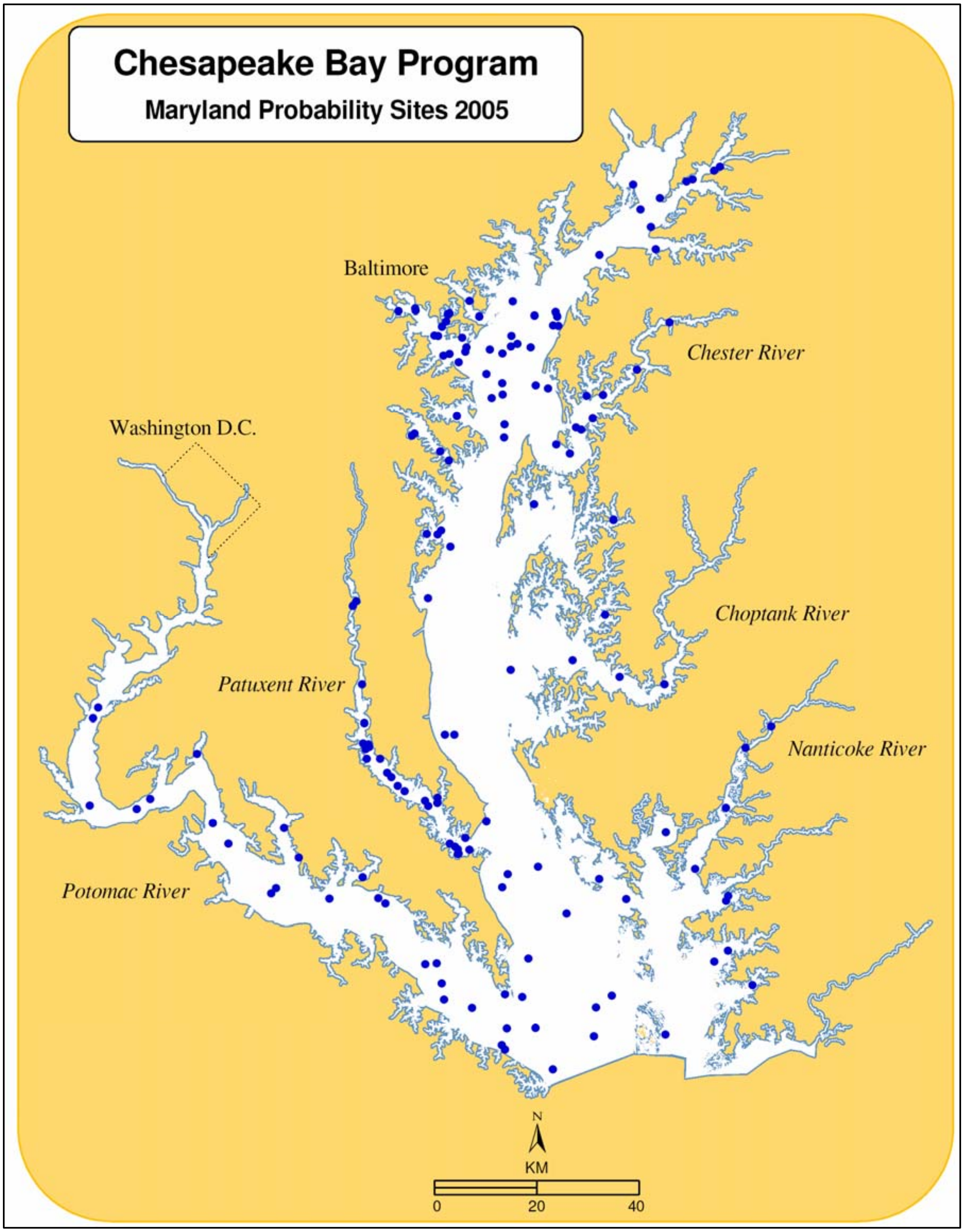

Figure 2-5. Maryland probability-based sampling sites for 2005

Table 2-3. Allocation of probability-based baywide samples, in and after 1995. Maryland areas exclude 676 km^2 of mainstem habitat deeper than 12 m. Virginia strata were sampled by the Virginia Chesapeake Bay Benthic Monitoring Program commencing in 1996.

State	Stratum	Area			Number of Samples
		km2	State %	Bay %	
Maryland	Deep Mainstem	676	10.8	5.8	0
	Mid Bay Mainstem	2,552	40.9	22.0	25
	Eastern Tributaries	534	8.6	4.6	25
	Western Tributaries	292	4.7	2.5	25
	Upper Bay Mainstem	785	12.6	6.8	25
	Patuxent River	128	2.0	1.1	25
	Potomac River*	1,276	20.4	11.0	25
	TOTAL	6,243	100.0	53.8	150
Virginia	Mainstem	4,120	76.8	35.5	25
	Rappahannock River	372	6.9	3.2	25
	York River	187	3.5	1.6	25
	James River	684	12.8	5.9	25
	TOTAL	5,363	100.0	46.2	100

*Excludes Virginia tidal creeks and district of Columbia waters

2.2 SAMPLE COLLECTION

2.2.1 Station Location

From July 1984 to June 1996, stations were located using Loran-C. After June 1996 stations were located using a differential Global Positioning System. The WGS84 coordinate system (undistinguishable in practice from NAD83) is currently used.

2.2.2 Water Column Measurements

Water column vertical profiles of temperature, conductivity, salinity, dissolved oxygen concentration (DO), and pH were measured at each site. Oxidation reduction potential (ORP) was measured prior to 1996. For fixed sites, profiles consisted of water quality measurements at 1 m intervals from surface to bottom at sites 7 m deep or less, and at 3 m intervals, with additional measurements at 1.5 m intervals in the vicinity of the pycnocline, at sites deeper than 7 m. Surface and bottom measurements were made at all other sampling sites. Table 2-4 lists the measurement methods used.

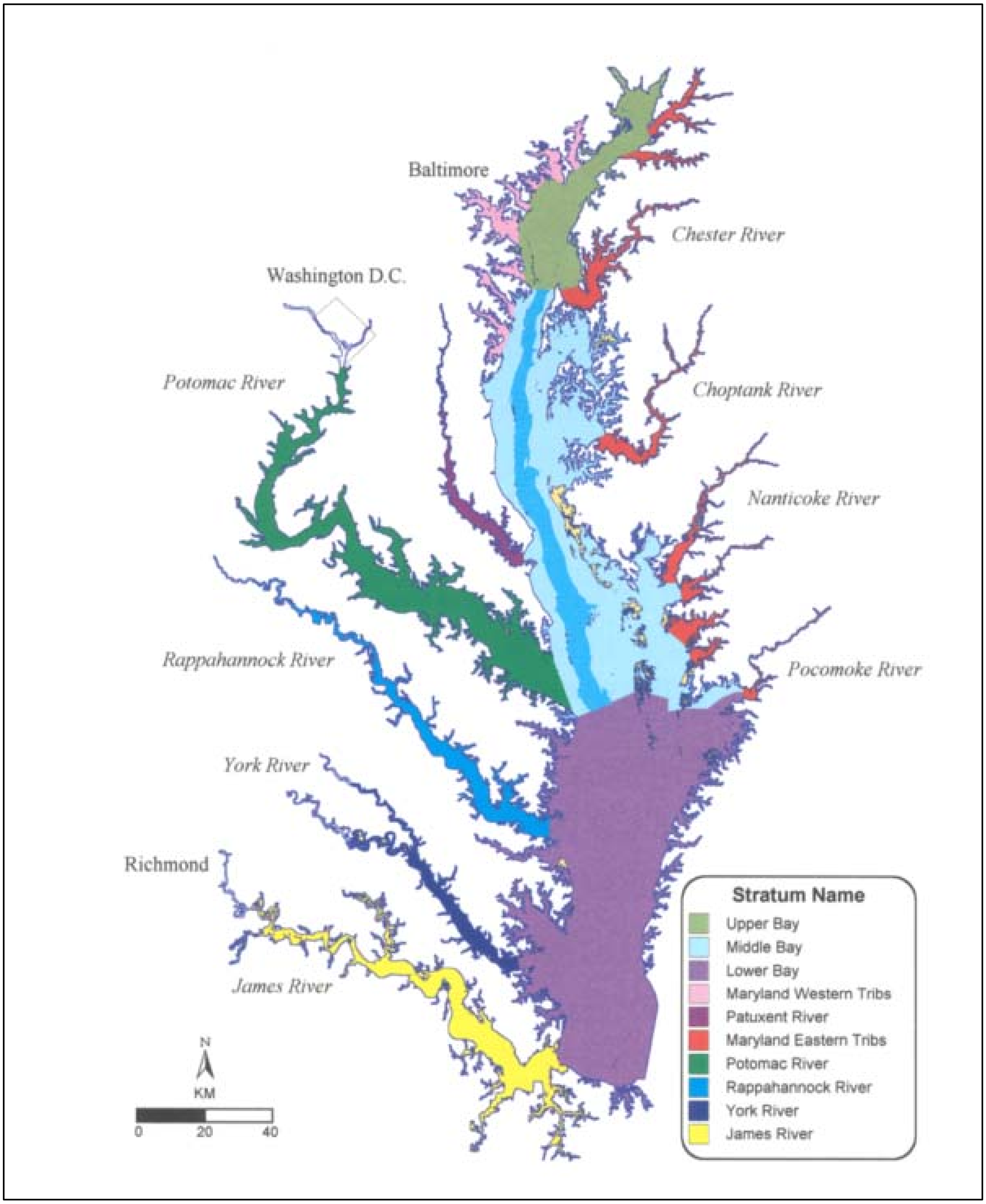

Figure 2-6. Chesapeake Bay stratification scheme

Table 2-4. Methods used to measure water quality parameters.

Parameter	Period	Method
Temperature	July 1984 to November 1984	Thermistor attached to Beckman Model RS5-3 salinometer
	December 1984 to December 1995	Thermistor attached to Hydrolab Surveyor II
	January 1996 to present	Thermistor attached to Hydrolab DataSonde 3 or (currently) YSI-6600 Sonde
Salinity and Conductivity	July to November 1984	Beckman Model RS5-3 salinometer toroidal conductivity cell with thermistor temperature compensation
	December 1984 to December 1995	Hydrolab Surveyor II nickel six-pin electrode-salt water cell block combination with automatic temperature compensation
	January 1996 to present	Hydrolab DataSonde 3 or (currently) YSI-6600 Sonde nickel six-pin electrode-salt water cell block combination with automatic temperature compensation
Dissolved Oxygen	July to November 1984	YSI Model 57 or Model 58 Oxygen Meter with automatic temperature and manual salinity compensation
	December 1984 to December 1995	Hydrolab Surveyor II membrane design probe with automatic temperature and salinity compensation
	January 1996 to present	Hydrolab DataSonde 3 or (currently) YSI-6600 Sonde membrane design probe with automatic temperature and salinity compensation
pH	July to November 1984	Orion analog pH meter with Ross glass combination electrode manually compensated for temperature
	December 1984 to December 1995	Hydrolab Surveyor II glass pH electrode and Lazaran reference electrode automatically compensated for temperature
	January 1996 to present	Hydrolab DataSonde 3 or (currently) YSI-6600 Sonde glass pH electrode and standard reference (STDREF) electrode automatically compensated for temperature
Oxidation Reduction Potential	December 1984 to December 1995	Hydrolab Surveyor II platinum banded glass ORP electrode

2.2.3 Benthic Samples

Samples were collected using four kinds of gear depending on the program element and habitat type. For the fixed site element (Table 2-1), a hand-operated box corer ("modified box corer"), which samples a 250 cm^2 area to a depth of 25 cm, was used in the nearshore shallow sandy habitats of the mainstem bay and tributaries. A Wildco box corer, which samples an area of 225 cm^2 to a depth of 23 cm, was used in shallow muddy or deep-water (> 5 m) habitats in the mainstem bay and tributaries. A Petite Ponar Grab, which samples 250 cm^2 to a depth of 7 cm, was used at the fixed site in the Nanticoke River to be consistent with previous sampling in the 1980s. At the two fixed sites first sampled in 1995 and at all probability-based sampling sites, a Young Grab, which samples an area of 440 cm^2 to a depth of 10 cm, was used.

Sample volume and penetration depth were measured for all samples; Wildco and hand-operated box cores penetrating less than 15 cm, and Young and Petite Ponar grabs penetrating less than 7 cm into the sediment were rejected and the site was re-sampled.

In the field, samples were sieved through a 0.5-mm screen using an elutriative process. Organisms and detritus retained on the screen were transferred into labeled jars and preserved in a 10% formaldehyde solution stained with Rose Bengal (a vital stain that aids in separating organisms from sediments and detritus).

Two surface-sediment sub-samples of approximately 120 ml each were collected for grain-size, carbon, and nitrogen analysis from an additional grab sample at each site. Surface sediment samples were frozen until they were processed in the laboratory.

2.3 LABORATORY PROCESSING

Organisms were sorted from detritus under dissecting microscopes, identified to the lowest practical taxonomic level (most often species), and counted. Oligochaetes and chironomids were mounted on slides and examined under a compound microscope for genus and species identification.

Ash-free dry weight biomass was determined by three comparable techniques during the sampling period. For samples collected from July 1984 to June 1985, biomass was directly measured using an analytical balance for major organism groups (e.g., polychaetes, molluscs, and crustaceans). Ash-free dry weight biomass was determined by drying the organisms to a constant weight at 60 °C and ashing in a muffle furnace at 500 °C for four hours. For samples collected between July 1985 and August 1993, a regression relationship between ash-free dry weight biomass and size of morphometric characters was defined for 22 species (Ranasinghe et al. 1993). The biomass of the 22 selected species was estimated from these regression relationships. These taxa (Table 2-5) were selected because they accounted for more than 85% of the abundance (Holland et al. 1988). After August 1993, ash-free dry weight biomass was measured directly for each species by drying the organisms to a constant weight at 60 °C and ashing in a muffle furnace at 500 °C for four hours and re-weighing (ash weight). The difference between the dry weight and the ash weight is the ash-free dry weight. Bivalves were crushed to open the shells and expose the animal to drying and ashing (shells included).

Table 2-5. Taxa for which biomass was estimated in samples collected between 1985 and 1993.

Polychaeta	Mollusca
Eteone heteropoda *Glycinde solitaria* *Heteromastus filiformis* *Marenzelleria viridis* *Neanthes succinea* *Paraprionospio pinnata* *Streblospio benedicti*	*Acteocina canaliculata* *Corbicula fluminea* *Gemma gemma* *Haminoe solitaria* *Macoma balthica* *Macoma mitchelli* *Mulinia lateralis* *Mya arenaria* *Rangia cuneata* *Tagelus plebeius*
Crustacea	
Cyathura polita *Gammarus* spp. *Leptocheirus plumulosus*	
Miscellaneous	
Carinoma tremaphoros *Micrura leidyi*	

Silt-clay composition and carbon and nitrogen content were determined for one of the two sediment sub-samples collected at each sampling site. The other sample was archived for quality assurance purposes (Scott et al. 1988). Sand and silt-clay particles were separated by wet-sieving through a 63-μm, stainless steel sieve and weighed using the procedures described in the Versar, Inc., Laboratory Standard Operating Procedures (Versar 1999). Carbon and nitrogen content of dried sediments was determined using an elemental analyzer. Sediment carbon content was measured with a Perkin-Elmer Model 240B analyzer from 1984 to 1988, and an Exeter Analytical Inc., Model CE-440 analyzer in and after 1995. The results from both instruments are comparable. Samples are combusted at high temperature (975 °C) and the carbon dioxide and nitrogen produced are measured by thermal conductivity detection. Prior to combustion, each sample is homogenized and oven-dried.

2.4 DATA ANALYSIS

Analyses for the fixed site and probability-based elements of LTB were both performed in the context of the Chesapeake Bay Program's benthic community restoration goals and the Benthic Index of Biotic Integrity (B-IBI) by which goal attainment is measured. The B-IBI, the Chesapeake Bay benthic community restoration goals, and statistical analysis methods for the two LTB elements are described below.

2.4.1 The B-IBI and the Chesapeake Bay Benthic Community Restoration Goals

The B-IBI is a multiple-attribute index developed to identify the degree to which a benthic assemblage meets the Chesapeake Bay Program's benthic community restoration goals (Ranasinghe et al. 1994a, updated by Weisberg et al. 1997; Alden et al. 2002). The B-IBI provides a means for comparing relative condition of benthic invertebrate assemblages across habitat types. It also provides a validated mechanism for integrating several benthic community attributes indicative of habitat "health" into a single number that measures overall benthic community condition.

The B-IBI is scaled from 1 to 5, and sites with values of 3 or more are considered to meet the restoration goals. The index is calculated by scoring each of several attributes as either 5, 3, or 1 depending on whether the value of the attribute at a site approximates, deviates slightly from, or deviates strongly from values found at the best reference sites in similar habitats, and then averaging these scores across attributes. The criteria for assigning these scores are numeric and depend on habitat. Data from seasons for which the B-IBI has not been developed were not used for B-IBI based assessment.

Benthic community condition was classified into four levels based on the B-IBI. Values less than or equal to 2.0 were classified as severely degraded; values from 2.0 to 2.6 were classified as degraded; values greater than 2.6 but less than 3.0 were classified as marginal; and values of 3.0 or more were classified as meeting the goals. Values in the marginal category do not meet the restoration goals, but they differ from the goals within the range of measurement error typically recorded between replicate samples.

2.4.2 Fixed Site Trend Analysis

Trends in condition at the fixed sites were identified using the nonparametric technique of van Belle and Hughes (1984). This procedure is based on the Mann-Kendall statistic and consists of a sign test comparing each value with all values measured in subsequent periods. The ratio of the Mann-Kendall statistic to its variance provides a normal deviate that is tested for significance. Alpha was set to 0.1 for these tests because of the low power for trend detection for biological data. An estimate of the magnitude of each significant trend was obtained using Sen's (1968) procedure which is closely related to the Mann-Kendall test. Sen's procedure identifies the median slope among all slopes between each value and all values measured in subsequent periods.

2.4.3 Probability-Based Estimation

The Maryland Bay was divided into three strata (Bay Mainstem, Potomac River, other tributaries and embayments) in 1994 (Table 2-2). It was divided into six strata in and after 1995 (Figure 2-4, Table 2-3). The Virginia Bay was divided into four strata, beginning in 1996 (Figure 2-6, Table 2-3).

To estimate the amount of area in the entire Bay that failed to meet the Chesapeake Bay benthic community restoration goals (P), we defined for every site *i* in stratum *h* a variable y_{hi} that had a value of 1 if the benthic community met the goals, and 0 otherwise. For each stratum, the estimated proportion of area meeting the goals, p_h, and its variance were calculated as the mean of the y_{hi}'s and its variance, as follows:

$$p_h = \bar{y}_h = \sum_{i=1}^{n_h} \frac{y_{hi}}{n_h} \tag{1}$$

and

$$\mathrm{var}\left(p_h\right) = s_h^2 = \sum_{i=1}^{n_h} \frac{\left(y_{hi} - \bar{y}_h\right)^2}{n_h - 1} \tag{2}$$

Estimates for strata were combined to achieve a statewide estimate as:

$$\hat{P}_{ps} = \bar{y}_{ps} = \sum_{h=1}^{6} W_h \bar{y}_h \tag{3}$$

where the weighting factor $W_h = A_h/A$; A_h is the total area of the *h*th stratum, and A is the combined area of all strata. The variance of (3) was estimated as:

$$\mathrm{var}\left(\hat{P}_{ps}\right) = \mathrm{var}\left(\bar{y}_{ps}\right) = \sum_{h=1}^{6} W_h^2 s_h^2 / n_h \tag{4}$$

The standard error for individual strata is estimated as the square root of (2), and for the combined strata, as the square root of (4).

3.0 RESULTS

3.1 TRENDS IN FIXED SITE BENTHIC CONDITION

Trend analysis is conducted on 27 fixed sites located throughout the Bay and its tributaries to assess whether benthic community condition is changing. The sites are sampled yearly in the spring and summer but the trend analysis is performed on the summer data only in order to apply the B-IBI (Weisberg et al. 1997; Alden et al. 2002). B-IBI calculations and trend analysis methods are described in Section 2.4.

The B-IBI is the primary measure used in trend analysis because it integrates several benthic community attributes into a measure of overall condition. It provides context for interpretation of observed trends because status has been calibrated to reference conditions. Significant trends that result in a change of status (sites that previously met the Chesapeake Bay benthic community restoration goals which now fail, or vice versa) are of greater management interest than trends which do not result in a change. As a first step in identifying causes of changes in condition, trends on individual attributes are identified and examined.

Table 3-1 presents trends in benthic community condition from 1985 to the present. Although the Maryland benthic monitoring component began sampling in 1984, data collected in the first year of our program were excluded from analysis to facilitate comparison of results with other components of the monitoring program. Several components of the Maryland program as well as the Virginia Benthic Monitoring Program did not start sampling until 1985. Twenty one-year (1985-2005) trends are presented for 23 of the 27 trend sites, 17-year trends are presented for two sites in Baltimore Harbor (Stations 201 and 202) first sampled in 1989, and 11-year trends are presented for two western shore tributaries (Back River, Station 203; and Severn River, Station 204) first sampled in 1995. Trend site locations are shown in Figure 2-1.

Statistically significant B-IBI trends ($p<0.1$) were detected at 8 of the 27 sites (Table 3-1). Trends in benthic community condition declined at 3 sites (significantly decreasing B-IBI trend) and improved at 5 sites, as in 2004. Currently, 10 sites meet the goals and 17 fail the goals. Initially, 10 sites met the goals and 17 failed the goals (Table 3-1). Although the number of sites that currently and initially met or failed the goals is the same, the status is not the same for all stations (Table 3-1). Six sites changed status in 2005 relative to the previous reporting year (Table 3-1 shaded areas). One site improved from degraded to marginal condition (Station 44), and five sites declined in condition. Of the five declining sites, three declined from meeting the goals to failing the goals (Station 51, 77, 23), one from marginal to degraded condition (Station 06), and one from degraded to severely degraded condition (Station 22). Declines in status at these stations were associated with wet conditions and increased hypoxia in 2003 and 2005.

Many of the trend sites showed reduced B-IBI scores in 2005 relative to the previous year. Lower B-IBI scores were obtained at locations prone to hypoxia: Baltimore

Harbor Stations 22, 23, and 202; Back River Station 203; Severn River Station 204; mainstem Stations 24 and 26; Patuxent River Stations 71 and 74; and Potomac River Station 51. B-IBI scores did not change at some stations: Baltimore Harbor Station 201, and Potomac River Stations 43 and 52. On the other hand, stations where low dissolved oxygen is usually not a problem, showed increased B-IBI scores in 2005 relative to the previous year: mainstem Stations 01, 06, and 15; Patuxent River Station 77; Potomac River Stations 36, 40, and 47; Nanticoke River Station 62; Choptank River Stations 64 and 66; Chester River Station 68; and Elk River Station 29.

Significant trends present with the analysis of 2004 data were still present with the addition of the 2005 data at 7 sites (Table 3-1). In addition to these trends, one trend that just emerged in 2004 disappeared with the addition of the 2005 data (Baltimore Harbor Station 23), and one trend that disappeared in 2004 was again significant in 2005 (Elk River Station 29).

Sites with improving B-IBI trends (Table 3-1) were located in the main stem of the Bay (Stations 15 and 26), Elk River (Station 29), Choptank River (Station 64), and Potomac River at St. Clements Island (Station 51). Sites with degrading B-IBI trends (Table 3-1) were located in the Severn River (Station 204), Patuxent River at Holland Cliff (Station 77), and Nanticoke River (Station 62).

Trends in community attributes that are components of the B-IBI are presented in Table 3-2 (mesohaline stations), Table 3-3 (oligohaline and tidal freshwater stations), and Appendix A.

3.2 BAYWIDE BOTTOM COMMUNITY CONDITION

The fixed site monitoring provides useful information about trends in the condition of benthic biological resources at 27 locations in the Maryland Bay but it does not provide an integrated assessment of the Bay's overall condition. The fixed sites were selected for trend monitoring because they are located in areas subject to management action and, therefore, are likely to undergo change. Because these sites were selected subjectively, there is no objective way of weighting them to obtain an unbiased estimate of Maryland baywide status.

An alternative approach for quantifying status of the bay, which was first adopted in the 1994 sampling program, is to use probability-based sampling to estimate the bottom area populated by benthos meeting the Chesapeake Bay benthic community restoration goals. Where the fixed site approach quantifies change at selected locations, the probability sampling approach quantifies the spatial extent of problems. While both approaches are valuable, developing and assessing the effectiveness of a Chesapeake Bay management strategy requires understanding the extent and distribution of problems throughout the Bay, instead of only assessing site-specific problems. Our probability-based sampling element is intended to provide that information, as well as a more widespread baseline data set for assessing the effects of unanticipated future contamination (e.g., oil or hazardous waste spills). Probability-based sampling information is also used for Chesapeake Bay aquatic life use support decisions under the Clean Water Act (Llansó et al. 2005b).

Probability-based sampling has been employed previously by LTB, but the sampled area included only 16% of the Maryland Bay (Ranasinghe et al. 1994a) which was insufficient to characterize the entire Bay. Probability-based sampling was also used in the Maryland Bay by the U.S. EPA Environmental Monitoring and Assessment Program (EMAP), and most recently by the National Coastal Assessment, but at a sampling density too low to develop precise condition estimates for the Maryland Bay. The 2005 sampling continues with efforts initiated in 1994 to develop area-based bottom condition statements for the Maryland Bay.

Estimates of tidal bottom area meeting the benthic community restoration goals are also included for the entire Chesapeake Bay. The estimates were enabled by including a probability-based sampling element in the Virginia Benthic Monitoring Program starting in 1996. The Virginia sampling is compatible and complementary to the Maryland effort and is part of a joint effort by the two programs to assess the extent of "healthy" tidal bottom baywide.

This section presents the results of the 2005 Maryland and Virginia probability-based sampling and provides twelve years (1994-2005) of benthic community monitoring in tidal waters of the Maryland Chesapeake Bay. The analytical methods for estimating the areal extent of bay bottom meeting the restoration goals were presented in Section 2.0. The physical data associated with the benthic samples (bottom water salinity, temperature, DO, and sediment silt-clay and organic carbon content) can be found in the Appendices Section of this report (Volume 2). Only summer data (July 15-September 30) are used for the probability-based assessments.

Of the 150 Maryland samples collected with the probability-based design in 2005, 65 met and 85 failed the Chesapeake Bay benthic community restoration goals (Figure 3-1), a decrease in the number of samples meeting the goals over that of 2004. Of the 250 probability samples collected in the entire Chesapeake Bay in 2005, 102 met and 148 failed the restoration goals. The Virginia sampling results are presented in Figure 3-2. In terms of number of sites meeting the goals in Chesapeake Bay, 2005 was a bad year (only 41% of the sites met the restoration goals), and together with 2003, these two years were the worst since probability-based sampling started in 1994.

The area with degraded benthos in the Maryland Bay increased in 2005 relative to 2004, and was similar to 2003 (Figure 3-3). The magnitude of the severely degraded condition increased substantially. Results from the individual sites were weighted based on the area of the stratum represented by the site in the stratified sampling design to estimate the tidal Maryland area failing the restoration goals. In 2005, 65% ($\pm$4% SE) of the Maryland Bay was estimated to fail the restoration goals. In 2004, the estimate was 52% ($\pm$5% SE). Expressed as area, 4,080$\pm$267 km^2 of the tidal Maryland Chesapeake Bay remained to be restored in 2005.

In 2005, the Potomac River, Patuxent River, and the Maryland mainstem were in the poorest condition among the six Maryland strata (Figure 3-4). The bottom area failing the restoration goals for each of these systems was in excess of 70%, much larger than the 64% estimated for 2004. The Potomac River had the largest percent degradation (Figure 3-4), and a large proportion of sites (40%) was azoic (no life) in 2005. Over the 1995-2005 time series, more than half of the tidal Potomac River (714-1,173 km^2) failed the restoration goals each year (Figure 3–5) and a large portion of that area, ranging from 48-93% (510-867 km^2, Table 3-4), was severely degraded.

The level of degradation in the Maryland mid-Bay mainstem continued to be high in 2005. The mid-Bay mainstem continued to have the largest amount of total failing area among the strata: 2,412 km^2 in 2005 (Table 3-4). The eastern shore tributaries of Maryland and the upper Bay mainstem exhibited low levels of degradation (Figure 3-4, Table 3-4). These two strata generally have good benthic community condition relative to the other bay strata, except in 2003 where unusually high levels of degradation were observed throughout the Bay (Figure 3-5). In 2005 percent degradation in the upper Bay mainstem was very low (4%), in part because of the distribution of the random sites. Sites with degraded condition in the upper Bay mainstem are generally concentrated in deep water at the mouth of the Chester River. In 2005, there were no random sites in this area (Figure 3-1), thus a majority of the upper Bay mainstem sites met the restoration goals. The upper Bay mainstem above the Chester River is not generally influenced by hypoxia.

In Virginia, percent degraded area in 2005 was large among strata, except for the James River (Figure 3-4, Table 3-4). Degraded condition was larger than in 2004 (Figure 3-6), as observed for most other Chesapeake Bay strata. The estimates of degradation prior to 2002 were revised for Virginia tidal waters. The revision included updates in the B-IBI that were implemented bay-wide in 2002 but had not been run on the older Virginia data. Changes to the estimates ranged between zero (no change) and 16%, with the largest change in the James River in 1996 and 2000. The new estimates are within the normal range of degradation observed for the Virginia strata.

The area of Chesapeake Bay estimated to fail the restoration goals increased substantially from 47% in 2004 to 59% in 2005, one of the largest estimates of degraded condition since baywide monitoring began in 1996 (Figure 3-7). The high estimates for 2005 were associated with high spring flows, which were responsible for high nutrient and sediment runoff leading to widespread hypoxia. Weighting results from the 250 probability sites in Maryland and Virginia, 59% ($\pm$4%) or 6,828$\pm$503 km^2 of the tidal Chesapeake Bay was estimated to fail the restoration goals in 2005 (Table 3-4). The percentage for previous years ranged from 47% ($\pm$4%) in 2004 to 59% ($\pm$ 5%) in 2003 (Table 3-4). Forty percent (4,664 Km^2) of the Chesapeake Bay bottom in 2005 was severely degraded, the largest percentage since 1996. No obvious trends in the percentage of area with marginal, moderate, or severely degraded condition were observed over the time series.

As reported in previous years, and for the period 1996-2005, five strata (Potomac River, Patuxent River, mid-Bay mainstem, Maryland upper western tributaries, and the

Virginia mainstem) had a large percentage (>67%) of sites failing the goals because of insufficient abundance or biomass of organisms relative to reference conditions (Table 3-5). Except for the Virginia mainstem, these strata also had a high percentage (>50%) of failing sites classified as severely degraded (Table 3-5). The Potomac and Patuxent rivers had the largest percentage of depauperate sites, failing for insufficient abundance or biomass. The Virginia mainstem also had a large percentage of depauperate sites, but this percentage was based on a comparatively small number of sites failing the restoration goals. The York and James rivers had the lowest percentages of depauperate sites. Low abundance, low biomass, and the level of widespread failure in most metrics necessary to classify a site as severely degraded would be expected on exposure to catastrophic events such as prolonged oxygen stress.

The Maryland eastern tributaries, James River, York River, and the upper Bay mainstem, had excess abundance, excess biomass, or both in over 25% of the failing sites (Table 3-6). Excess abundance and excess biomass are phenomena usually associated with eutrophic conditions and organic enrichment of the sediment in the absence of low dissolved oxygen stress.

Table 3-1. Summer trends in benthic community condition, 1985-2005. Trends were identified using the van Belle and Hughes (1984) procedure. Current mean B-IBI and condition are based on 2003-2005 values. Initial mean B-IBI and condition are based on 1985-1987 values, except where noted. NS: not significant; (a): 1989-1991 initial condition; (b): 1995-1997 initial condition. Shaded areas highlight changes in trend or condition over those reported for 2004.

Station	Trend Significance	Median Slope (B-IBI units/yr)	Current Condition (2003-2005)	Initial Condition (1985-1987 unless otherwise noted)
Potomac River				
36	NS	0.00	2.44 (Degraded)	3.14 (Meets Goal)
40	NS	0.00	3.18 (Meets Goal)	2.80 (Marginal)
43	NS	0.00	3.53 (Meets Goal)	3.76 (Meets Goal)
44	NS	0.00	2.73 (Marginal)	2.80 (Marginal)
47	NS	0.00	3.80 (Meets Goal)	3.89 (Meets Goal)
51	$p < 0.01$	0.03	2.63 (Degraded)	2.43 (Degraded)
52	NS	0.00	1.15 (Severely Degraded)	1.37 (Severely Degraded)
Patuxent River				
71	NS	0.00	2.11 (Degraded)	2.52 (Degraded)
74	NS	0.00	3.27 (Meets Goal)	3.78 (Meets Goal)
77	$p < 0.01$	−0.06	2.60 (Degraded)	3.76 (Meets Goal)
79	NS	0.00	2.67 (Marginal)	2.75 (Marginal)
Choptank River				
64	$p < 0.05$	0.03	3.56 (Meets Goal)	2.78 (Marginal)
66	NS	0.00	2.96 (Marginal)	2.60 (Degraded)
Maryland Mainstem				
01	NS	0.00	2.63 (Marginal)	2.93 (Marginal)
06	NS	0.00	2.15 (Degraded)	2.56 (Degraded)
15	$p < 0.01$	0.04	3.37 (Meets Goal)	2.22 (Degraded)
24	NS	0.00	3.26 (Meets Goal)	3.04 (Meets Goal)
26	$p < 0.01$	0.02	3.62 (Meets Goal)	3.16 (Meets Goal)
Maryland Western Shore Tributaries				
22	NS	−0.01	1.58 (Severely Degraded)	2.08 (Degraded)
23	NS	0.00	2.60 (Degraded)	2.49 (Degraded)
201	NS	0.00	1.40 (Severely Degraded)	1.10 (Severely Degraded) (a)
202	NS	0.00	1.31 (Severely Degraded)	1.40 (Severely Degraded) (a)
203	NS	0.00	2.33 (Degraded)	2.08 (Degraded) (b)
204	$p < 0.001$	−0.17	2.41 (Degraded)	3.67 (Meets Goal) (b)
Maryland Eastern Shore Tributaries				
29	$p < 0.1$	0.01	2.48 (Degraded)	2.38 (Degraded)
62	$p < 0.01$	−0.03	3.13 (Meets Goal)	3.42 (Meets Goal)
68	NS	0.00	3.67 (Meets Goal)	3.51 (Meets Goal)

Table 3-2. Summary trends in benthic community attributes at mesohaline stations 1985-2005. Monotonic trends were identified using the van Belle and Hughes (1984) procedure. ⇑: Increasing trend; ⇓: Decreasing trend. *: $p < 0.1$; **: $p < 0.05$; ***: $p < 0.01$; shaded trend cells indicate increasing degradation; unshaded trend cells indicate improving conditions; (a): trends based on 1989-2005 data; (b): trends based on 1995-2005 data; (c): attribute trend based on 1990-2005 data; (d): attributes are used in B-IBI calculations when species specific biomass is unavailable; NA: attribute is not part of the reported B-IBI. Blanks indicate no trend (not significant). See Appendix A for further detail.

Station	B-IBI	Abundance	Biomass	Shannon Diversity	Indicative Abundance	Sensitive Abundance	Indicative Biomass (c)	Sensitive Biomass (c)	Abundance Carnivore/ Omnivores
Potomac River									
43		⇓*	⇓ ***		⇑ ***	(d)	NA		NA
44		⇓ ***	⇓ *			(d)	NA		NA
47					⇑ ***	⇓ *** (d)	NA	⇓ **	NA
51	⇑ ***		⇓ ***	⇑ ***	⇓ ***	⇑ **	NA		
52		⇓ ***	⇓ ***	⇓ **	(d)	(d)			⇓ **
Patuxent River									
71		⇓ ***	⇓ ***		⇓ *** (d)	⇓ * (d)	⇓ ***		⇑ ***
74		⇑ ***	⇓ ***	⇓ *	⇑ **	⇓ *** (d)	NA	⇓ ***	NA
77	⇓ ***		⇓ ***		⇑ ***	(d)	NA	⇑ *	NA
Choptank River									
64	⇑ **	⇑ *	⇑ *		(d)	⇑ * (d)		⇓ **	
Maryland Mainstem									
01							NA	NA	
06		⇑ **					NA	NA	
15	⇑ ***	⇑ **			⇓ ***		NA	NA	⇑ *
24		⇓ **	⇓ **	⇓ ***	⇓ *** (d)	(d)			⇑ ***
26	⇑ ***					(d)	NA		NA
Maryland Western Shore Tributaries									
22			⇓ **	⇓ **	⇑ ***	(d)	NA		NA
23		⇓ ***				⇑ *** (d)	NA		NA
201(a)		⇓ ***				(d)	NA		NA
202(a)		⇓ **				(d)	NA	⇑ **	NA
204(b)	⇓ ***		⇓ ***		⇑ ** (d)	⇓ * (d)	⇑ ***	⇓ ***	
Maryland Eastern Shore Tributaries									
62	⇓ ***		⇓ **	⇓ ***		⇓ ** (d)	NA		NA
68			⇑ **			⇑ *** (d)	NA		NA

Table 3-3. Summary trends in benthic community attributes at oligohaline and tidal freshwater stations 1985-2005. Monotonic trends were identified using the van Belle and Hughes (1984) procedure. ⇑: Increasing trend; ⇓: Decreasing trend. *: p< 0.1; **: p< 0.05; ***: p< 0.01; shaded trend cells indicate increasing degradation; unshaded trend cells indicate improving conditions; (a): trends based on 1995-2005 data; NA: attribute not calculated. Blanks indicate no trend (not significant). See Appendix A for further detail.

Station	B-IBI	Abundance	Tolerance Score	Freshwater Indicative Abundance	Oligohaline Indicative Abundance	Oligohaline Sensitive Abundance	Tanypodinae to Chironomidae Ratio	Abundance Deep Deposit Feeders	Abundance Carnivore/ Omnivores
Potomac River									
36				⇑ *	NA	NA	NA	⇑ **	NA
40				NA				NA	
Patuxent River									
79		⇑ **		⇓ *	NA	NA	NA		NA
Choptank River									
66		⇑ ***	⇑ ***	NA			⇑ ***	NA	⇑ **
Maryland Western Shore Tributaries									
203(a)			⇓ **	NA			⇑ ***	NA	⇑ **
Maryland Eastern Shore Tributaries									
29	⇑ *		⇓ **	NA	⇓ **			NA	⇑ ***

Table 3-4. Estimated tidal area (km^2) failing to meet the Chesapeake Bay benthic community restoration goals in the Chesapeake Bay, Maryland, Virginia, and each of the 10 sampling strata. In this table, the area of the mainstem deep trough is included in the estimates for the severely degraded portion of Chesapeake Bay, Maryland tidal waters, and Maryland mid-bay mainstem; (a) revised data (see text, p. 3-4).

Region	Year	Severely Degraded	Degraded	Marginal	Total Failing	% Failing
Chesapeake Bay	1996	3,080	1,388	1,056	5,524	47.6 (a)
	1997	2,941	2,072	877	5,890	50.7 (a)
	1998	3,771	1,689	1,271	6,731	58.0 (a)
	1999	3,164	1,660	1,020	5,844	50.3 (a)
	2000	2,704	1,538	1,474	5,715	49.2 (a)
	2001	3,123	1,187	1,749	6,060	52.2 (a)
	2002	3,424	1,584	1,170	6,178	53.2
	2003	3,351	2,537	964	6,852	59.0
	2004	2,902	1,940	650	5,492	47.3
	2005	4,664	1,550	614	6,828	58.8
Maryland Tidal Waters	1994	2,684	1,152	497	4,332	66.5
	1995	2,872	605	182	3,659	58.6
	1996	2,614	700	155	3,469	55.6
	1997	2,349	697	483	3,529	56.5
	1998	2,663	1,016	623	4,302	68.9
	1999	2,423	1,137	374	3,935	63.0
	2000	2,455	1,137	236	3,828	61.3
	2001	2,313	582	644	3,538	56.7
	2002	2,444	713	928	4,086	65.4
	2003	2,571	1,288	228	4,086	65.4
	2004	2,037	985	226	3,248	52.0
	2005	2,771	1,014	295	4,080	65.3
Virginia Tidal Waters	1996	466	688	901	2,055	38.3 (a)
	1997	592	1,375	394	2,361	44.0 (a)
	1998	1,107	673	648	2,429	45.3 (a)
	1999	741	523	646	1,909	35.6 (a)
	2000	249	401	1,238	1,888	35.2 (a)
	2001	810	606	1,106	2,522	47.0 (a)
	2002	980	871	242	2,092	39.0
	2003	780	1,249	736	2,766	51.6
	2004	866	955	424	2,245	41.9
	2005	1,893	536	319	2,748	51.2

Table 3-4. (Continued)

Region	Year	Severely Degraded	Degraded	Marginal	Total Failing	% Failing
Potomac River	1994	793	330	0	1,123	60.7
	1995	510	153	51	714	56.0
	1996	714	51	0	765	60.0
	1997	561	204	102	867	68.0
	1998	561	510	102	1,173	92.0
	1999	663	153	102	918	72.0
	2000	612	255	0	867	68.0
	2001	612	357	51	1,020	80.0
	2002	561	204	153	918	72.0
	2003	867	153	0	1,020	80.0
	2004	663	153	0	816	64.0
	2005	867	255	0	1,122	88.0
Patuxent River	1995	51	10	5	67	52.0
	1996	41	20	0	61	48.0
	1997	20	5	10	36	28.0
	1998	31	26	5	61	48.0
	1999	20	10	10	41	32.0
	2000	51	26	10	87	68.0
	2001	56	15	20	92	72.0
	2002	36	26	20	82	64.0
	2003	51	46	0	97	76.0
	2004	15	67	0	82	64.0
	2005	51	36	5	92	72.0
Maryland Upper Western Tributaries	1995	58	47	23	129	44.0
	1996	117	47	0	164	56.0
	1997	105	23	12	140	48.0
	1998	94	23	12	129	44.0
	1999	117	47	12	175	60.0
	2000	140	70	0	211	72.0
	2001	70	12	47	129	44.0
	2002	94	47	47	187	64.0
	2003	47	105	23	175	60.0
	2004	70	117	0	187	64.0
	2005	140	47	0	187	64.0

Table 3-4. (Continued)

Region	Year	Severely Degraded	Degraded	Marginal	Total Failing	% Failing
Maryland Eastern Tributaries	1995	107	128	0	235	44.0
	1996	21	150	21	192	36.0
	1997	43	64	21	128	24.0
	1998	21	64	64	150	28.0
	1999	43	150	86	278	52.0
	2000	64	150	21	235	44.0
	2001	128	64	86	278	52.0
	2002	64	107	64	235	44.0
	2003	128	214	0	342	64.0
	2004	86	107	21	214	40.0
	2005	86	64	86	235	44.0
Maryland Upper Bay Mainstem	1995	345	63	0	408	52.0
	1996	126	126	31	283	36.0
	1997	126	94	31	251	32.0
	1998	157	188	31	377	48.0
	1999	188	63	63	314	40.0
	2000	94	126	0	220	28.0
	2001	157	31	31	220	28.0
	2002	94	126	31	251	32.0
	2003	188	157	0	345	44.0
	2004	220	31	0	251	32.0
	2005	31	0	0	31	4.0
Maryland Mid Bay Mainstem	1995	1,799	204	102	2,106	65.2
	1996	1,595	306	102	2,004	62.1
	1997	1,493	306	306	2,106	65.2
	1998	1,799	204	408	2,412	74.7
	1999	1,391	715	102	2,208	68.4
	2000	1,493	510	204	2,208	68.4
	2001	1,289	102	408	1,799	55.7
	2002	1,595	204	613	2,412	74.7
	2003	1,289	613	204	2,106	65.2
	2004	983	510	204	1,697	52.6
	2005	1,595	613	204	2,412	74.7

Table 3-4. (Continued)

Region	Year	Severely Degraded	Degraded	Marginal	Total Failing	% Failing
Virginia Mainstem	1996	165	494	824	1,483	36.0 (a)
	1997	165	1,154	330	1,648	40.0 (a)
	1998	824	330	494	1,648	40.0
	1999	494	165	494	1,154	28.0 (a)
	2000	0	165	1,154	1,318	32.0
	2001	494	330	989	1,813	44.0 (a)
	2002	659	659	165	1,483	36.0
	2003	494	824	659	1,977	48.0
	2004	659	659	330	1,648	40.0
	2005	1,483	330	165	1,977	48.0
Rappahannock River	1996	119	60	0	179	48.0
	1997	149	74	15	238	64.0 (a)
	1998	60	134	45	238	64.0 (a)
	1999	89	89	74	253	68.0 (a)
	2000	149	104	15	268	72.0 (a)
	2001	30	60	60	149	40.0 (a)
	2002	134	45	0	179	48.0
	2003	89	104	0	194	52.0
	2004	60	89	30	179	48.0
	2005	253	60	30	343	92.0
York River	1996	45	52	22	120	64.0 (a)
	1997	60	37	22	120	64.0 (a)
	1998	60	45	0	105	56.0 (a)
	1999	75	22	22	120	64.0 (a)
	2000	45	22	15	82	44.0 (a)
	2001	67	52	30	150	80.0
	2002	22	30	22	75	40.0
	2003	60	75	22	157	84.0
	2004	37	15	37	90	48.0
	2005	75	37	15	127	68.0
James River	1996	137	82	55	273	40.0 (a)
	1997	219	109	27	355	52.0 (a)
	1998	164	164	109	437	64.0 (a)
	1999	82	246	55	383	56.0 (a)
	2000	55	109	55	219	32.0 (a)
	2001	219	164	27	410	60.0
	2002	164	137	55	355	52.0
	2003	137	246	55	437	64.0
	2004	109	191	27	328	48.0
	2005	82	109	109	301	44.0

Table 3-5. Sites severely degraded (B-IBI≤2) and failing the restoration goals (scored at 1.0) for insufficient abundance, insufficient biomass, or both as a percentage of sites failing the goals (B-IBI<3), 1996 to 2005. Strata are listed in decreasing percent order of sites with insufficient abundance/biomass.

Stratum	Sites Severely Degraded		Sites Failing the Goals Due to Insufficient Abundance, Biomass, or Both	
	Number of Sites	As Percentage of Sites Failing the Goals	Number of Sites	As Percentage of Sites Failing the Goals
Potomac River	131	70.4	149	80.1
Patuxent River	73	51.0	110	76.9
Mid Bay Mainstem	76	53.1	107	74.8
Western Tributaries	85	59.0	97	67.4
Virginia Mainstem	33	33.7	66	67.3
Rappahannock River	76	51.0	90	60.4
Upper Bay Mainstem	44	54.3	47	58.0
Eastern Tributaries	32	29.9	53	49.5
York River	73	47.7	61	39.9
James River	50	39.1	45	35.2

Table 3-6. Sites failing the restoration goals (scored at 1.0) for excess abundance, excess biomass, or both as a percentage of sites failing the goals (B-IBI<3), 1996 to 2005. Strata are listed in decreasing percent order of sites with excess abundance/biomass.

Stratum	Number of Sites	As Percentage of Sites Failing the Goals
Eastern Tributaries	33	30.8
James River	37	28.9
Upper Bay Mainstem	21	25.9
York River	39	25.5
Western Tributaries	31	21.5
Rappahannock River	25	16.8
Mid Bay Mainstem	22	15.4
Potomac River	23	12.4
Patuxent River	17	11.9
Virginia Mainstem	9	9.2

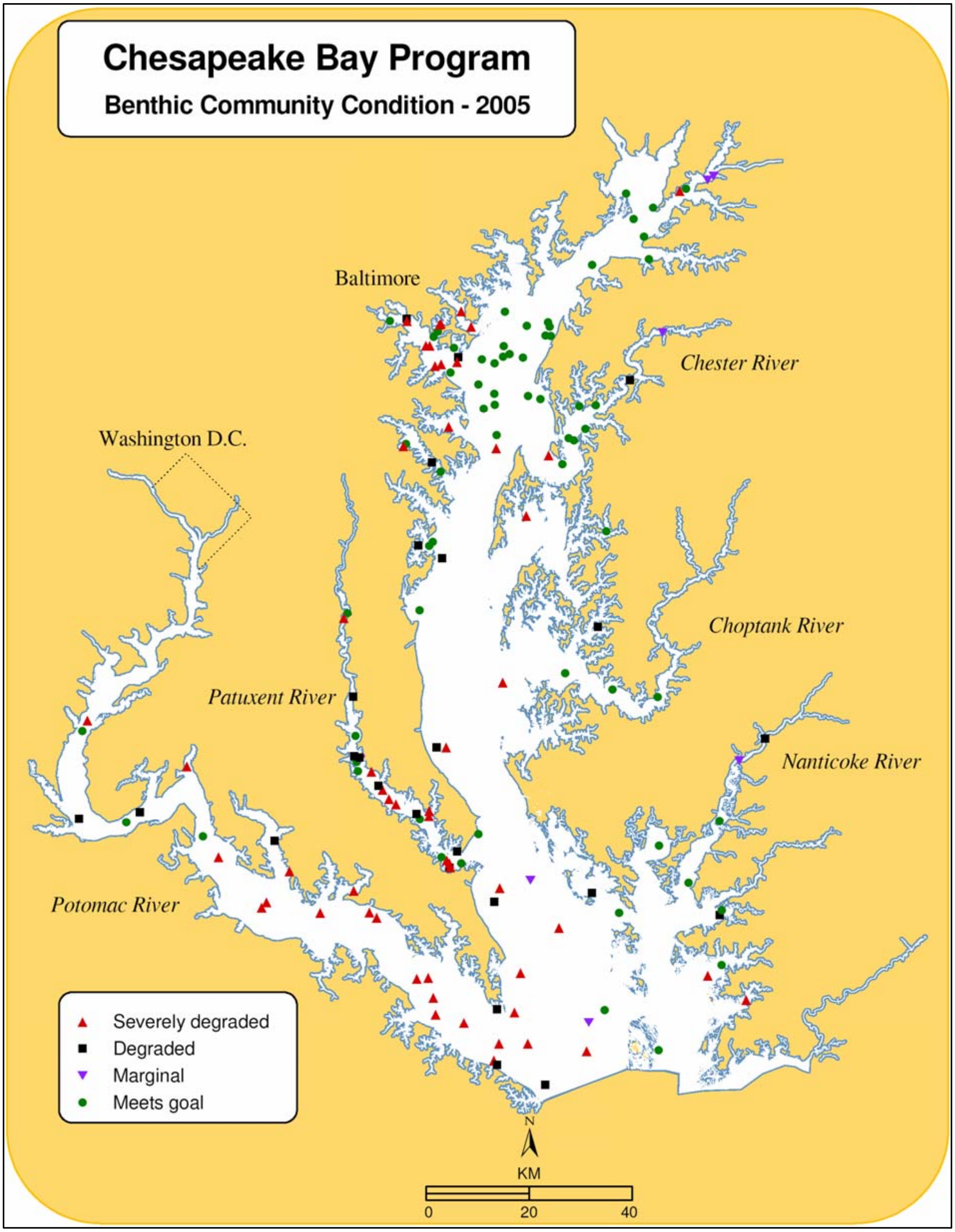

Figure 3-1. Results of probability-based benthic sampling of the Maryland Chesapeake Bay and its tidal tributaries in 2005. Each sample was evaluated in context of the Chesapeake Bay benthic community restoration goals.

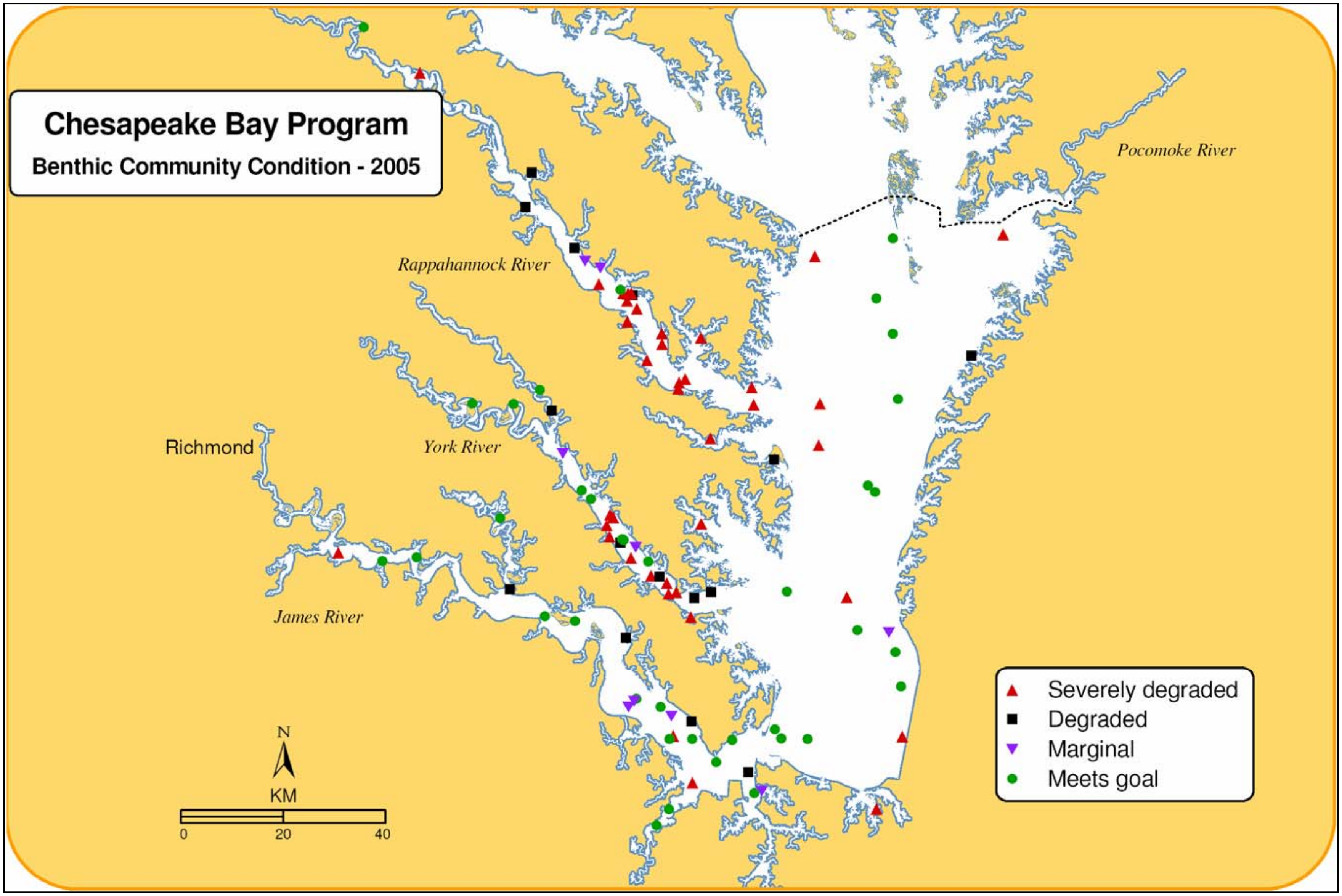

Figure 3-2. Results of probability-based benthic sampling of the Virginia Chesapeake Bay and its tidal tributaries in 2005. Each sample was evaluated in context of the Chesapeake Bay benthic community restoration goals.

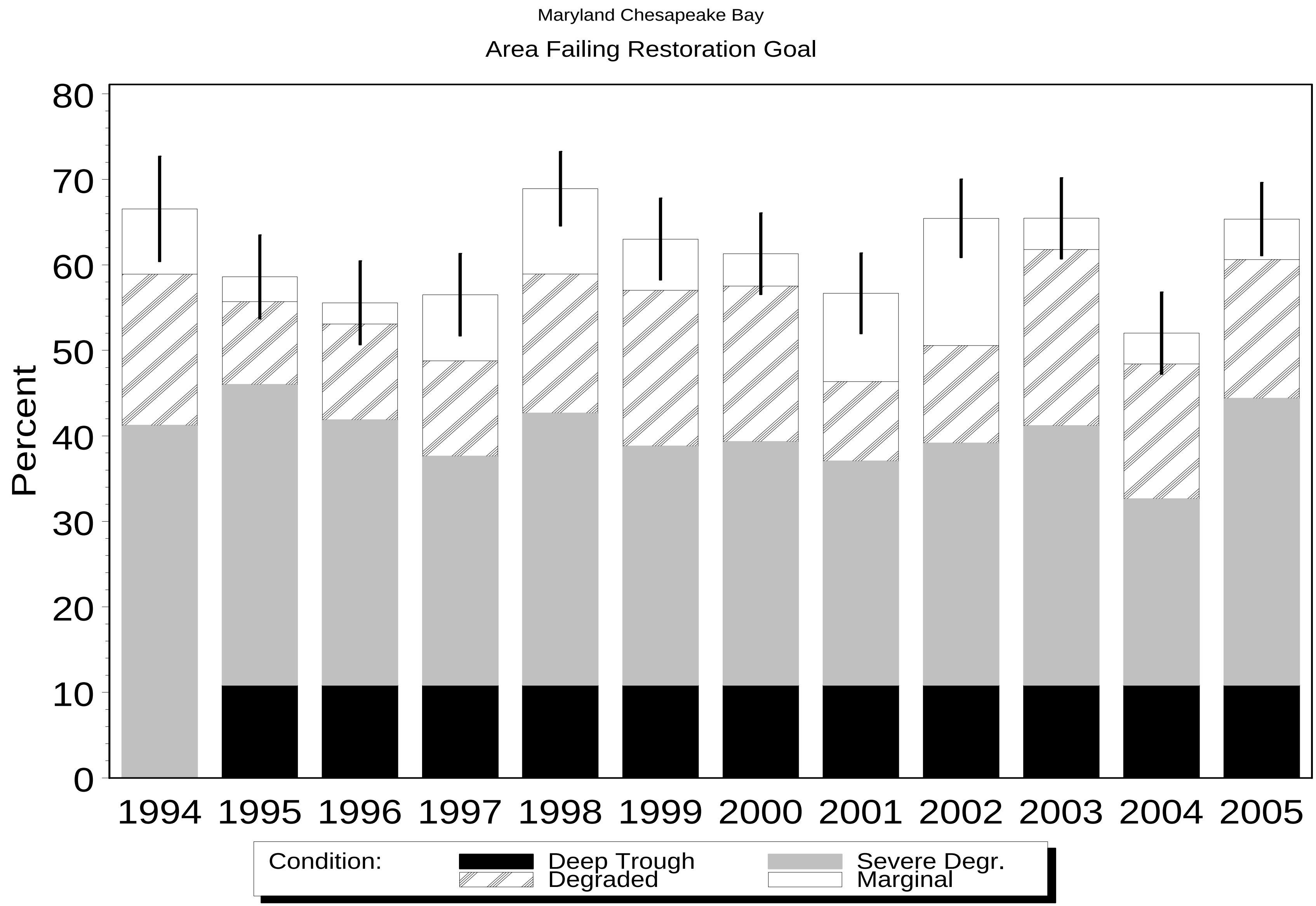

Figure 3-3. Proportion of the Maryland Bay failing the Chesapeake Bay benthic community restoration goals from 1994 to 2005. The error bars indicate ± 1 standard error. The mainstem deep trough was sampled in 1994 and found to be mostly azoic; it is included in the severely degraded condition in 1994, but was excluded from sampling in subsequent years.

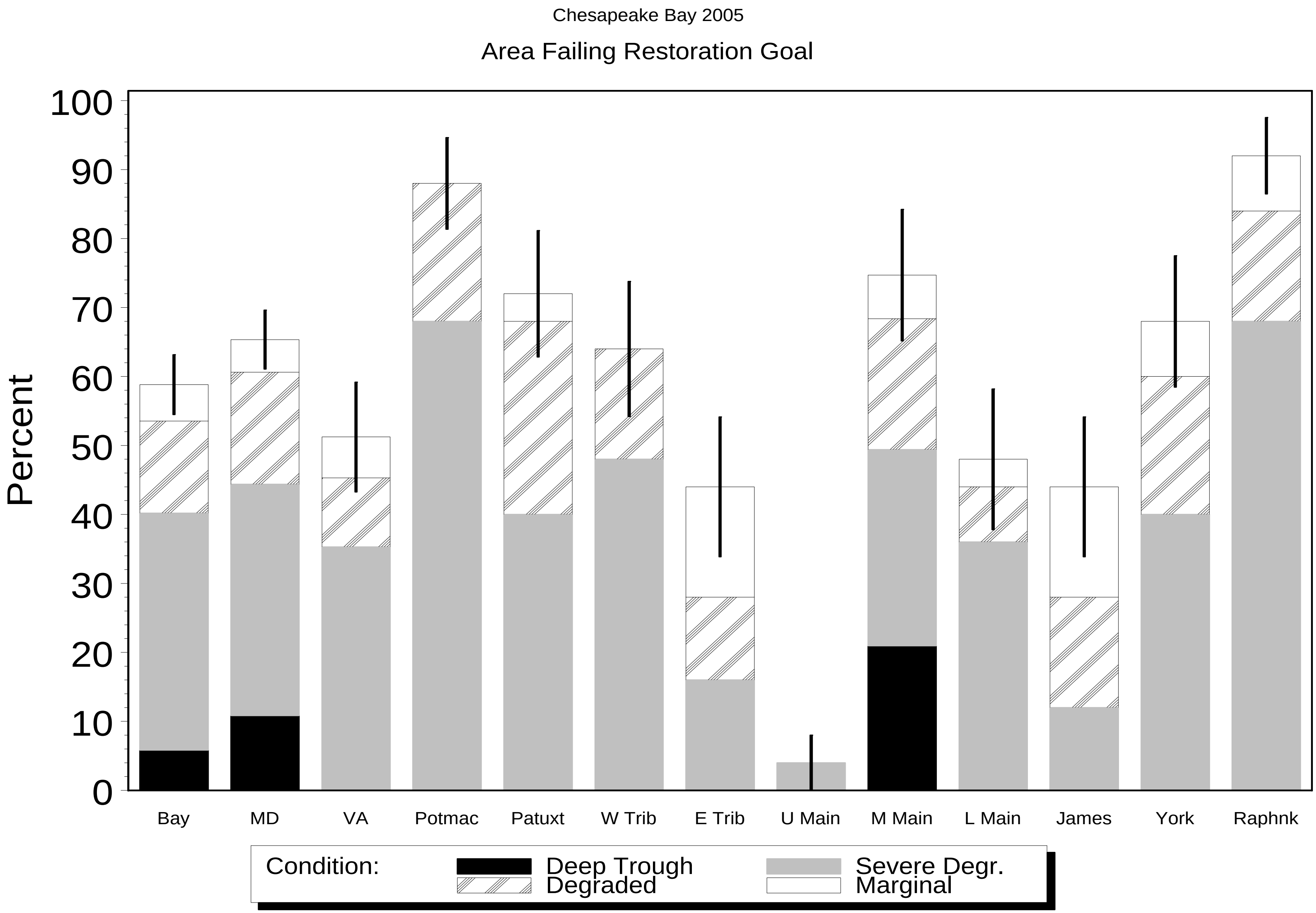

Figure 3-4. Proportion of the Chesapeake Bay, Maryland, Virginia, and the 10 sampling strata failing the Chesapeake Bay benthic community restoration goals in 2005. The error bars indicate ± 1 standard error.

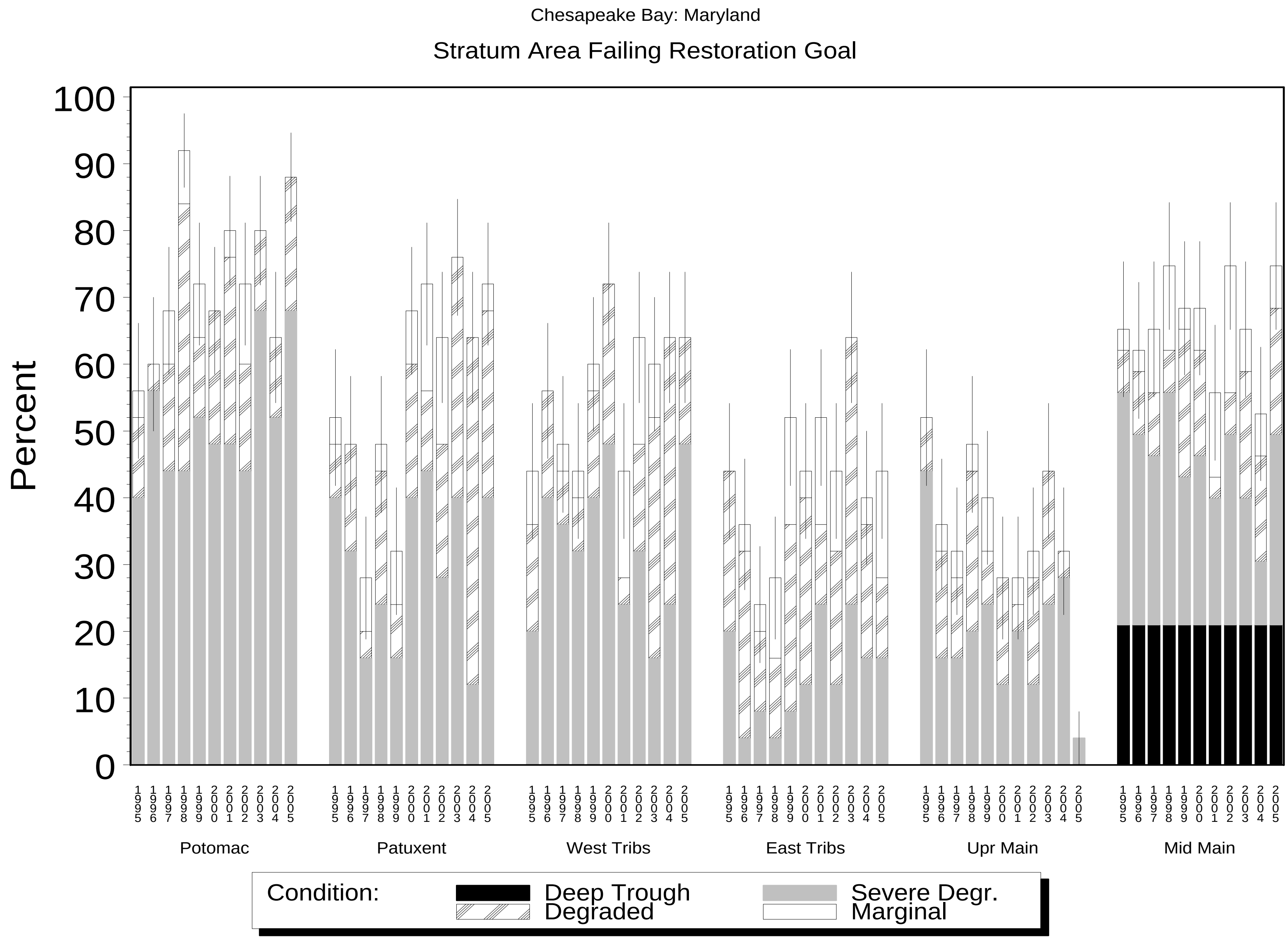

Figure 3-5. Proportion of the Maryland sampling strata failing the Chesapeake Bay benthic community restoration goals, 1995 to 2005. The error bars indicate ± 1 standard error.

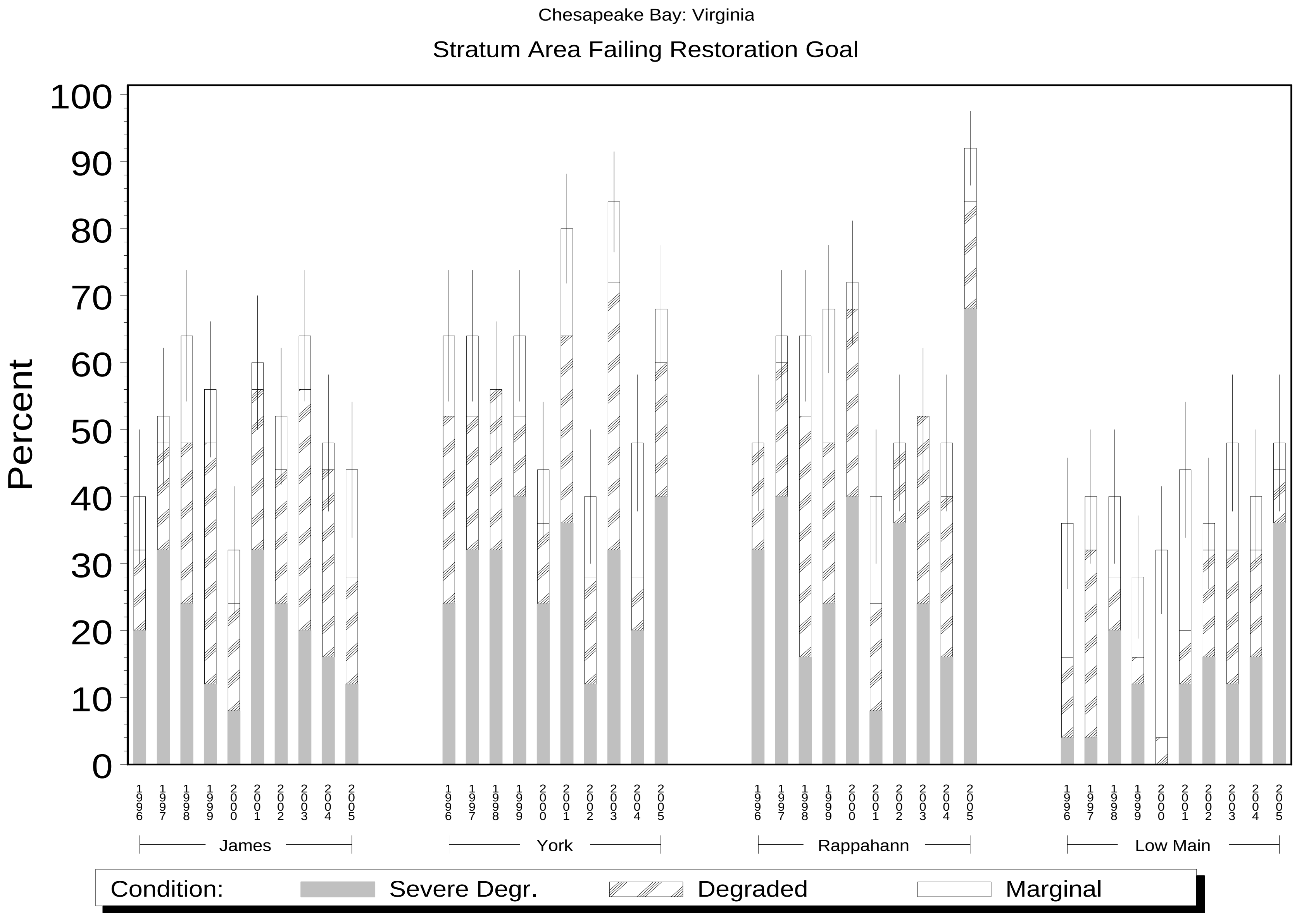

Figure 3-6. Proportion of the Virginia sampling strata failing the Chesapeake Bay benthic community restoration goals, 1996 to 2005. The error bars indicate ± 1 standard error.

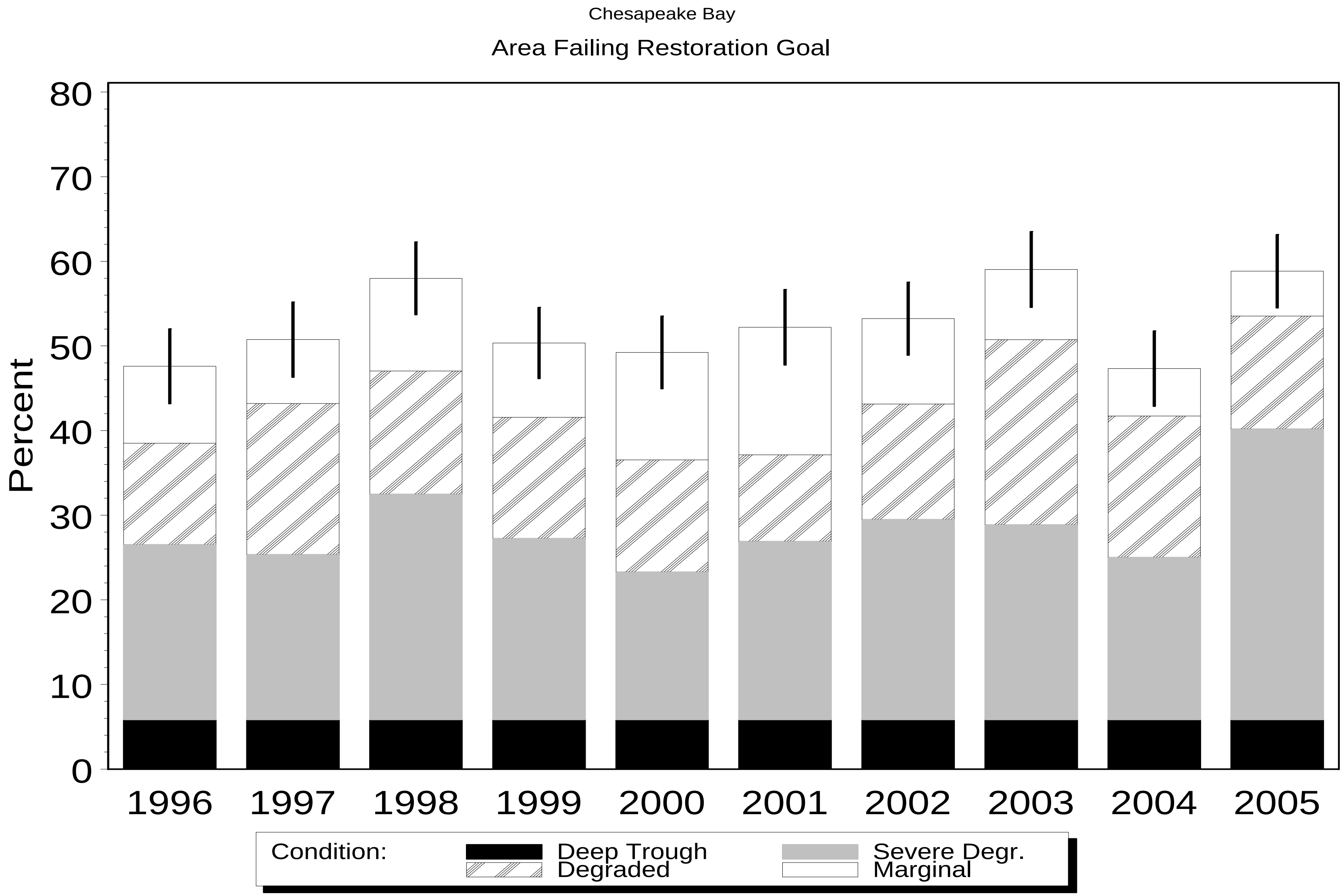

Figure 3-7. Proportion of the Chesapeake Bay failing the Chesapeake Bay benthic community restoration goals, 1996 to 2005. The error bars indicate ± 1 standard error.

4.0 DISCUSSION

Estimates of benthic community degradation for the Maryland portion of the Bay were higher in 2005 than in the preceding year and comparable to those of wet years. Overall, 65% of the Maryland tidal waters failed the Chesapeake Bay benthic community restoration goals in 2005. The higher estimate in 2005 contrasts with a low estimate of 52% in 2004. For the Chesapeake Bay, the area estimated to fail the restoration goals increased from 47% in 2004 to 59% in 2005. The higher estimates for 2005 were associated with high spring flows in the Bay's tributaries, which were responsible for high nutrient and sediment run off, leading to widespread hypoxia. It is the intensity of the spring flow that is most closely associated with benthic community condition later in the year. Inter-annual variability in river flow patterns influences water quality and benthic community condition. High spring flows have been theorized to cause earlier and spatially more extensive stratification within the Bay, leading to more extensive hypoxia (Tuttle et al. 1987). River flow was also above normal in 2004, but the heaviest precipitation occurred in September, after the summer period that usually influences most benthic community condition in the Bay. Thus the extent of degradation in 2004 was not as severe as in 2005.

Over the past decade, the area with degraded benthic community condition has varied with changes in hydrology (dry versus wet years) and year-to-year fluctuations in the frequency, severity, and extent of hypoxia. Although years with low run-off fare better for aquatic resources in Chesapeake Bay than wet years, the area with degraded benthic communities in Chesapeake Bay continues to be large in any given year. Even though hypoxic conditions may be mild, the extent of degradation for some monitoring strata continues to be large because of accumulated organic matter and altered benthic communities. It will probably take sustained management efforts over an extended period of time to bring back a more balanced community of benthic organisms and see significant baywide improvements in benthic condition. Excess organic matter from phytoplankton blooms in combination with hypoxia primarily enhances the growth and reproduction of small pollution tolerant organisms. It is the excess of nutrients in sediments that may continue to be a problem in many areas of the Bay even after improvements in dissolved oxygen conditions occur.

Thirty-two percent of the degraded Chesapeake Bay bottom in 2005 (2,164 km^2) was marginally to moderately impaired. In the Maryland portion of the Bay, 32% of the degraded bottom (1,309 km^2) was also marginally to moderately impaired. Of the additional 2,771 km^2 of Maryland Bay bottom supporting severely degraded benthic communities, 676 km^2 were located in the deep (>12m) mainstem that is perennially anoxic and probably beyond the scope of present mitigation efforts. The area with marginal to moderate degradation would be expected to show the first signs of improvement as nutrient reduction efforts are implemented baywide. However, no obvious trends in the percentage of area with marginal or moderate degradation were observed over the time series.

In 2005, the percent area with severely degraded condition was one of the highest of the time series in Maryland (45% or 2,771 Km^2), and the highest in Chesapeake Bay since 1996 (40% or 4,664 km^2). An unusually large proportion of the random benthic sites was azoic (no macrofauna), pointing to severe hypoxia or anoxia during the summer months. With the exception of the James River, the major tributaries (Potomac, Patuxent, Rappahannock, and York rivers) and the Maryland mainstem were in the poorest condition. The upper Bay maistem was in best condition. The upper Bay maistem above the Chester River is not generally influenced by hypoxia.

Trends in fixed-site benthic condition remained mostly unchanged in 2005 relative to the previous reporting year. Improving benthic community condition continued in the mainstem of the Bay (Stations 15 and 26), Elk River (Station 29), Choptank River (Station 64), and Potomac River at St. Clements Island (Station 51). Declining benthic community condition continued in the Severn River (Station 204), Patuxent River at Holland Cliff (Station 77), and Nanticoke River (Station 62). The most important difference between 2005 and 2004 was a general decline in benthic condition at locations prone to hypoxia, such as at trend sites in Baltimore Harbor, Back River, Severn River, and lower Patuxent and Potomac rivers. The two upper Maryland mainstem sites (Stations 24 and 26) also showed declines in B-IBI scores in 2005, although it is not clear which factors (e.g., low dissolved oxygen, reduced salinity or increased sediment loads associated with the high spring flows) may have been responsible for the declines. None of the trend sites in the eastern shore tributaries showed declines in the B-IBI.

We have discussed patterns of degradation and sources of stress affecting benthic communities in Chesapeake Bay in previous reports. We refer the reader to these reports (e.g., Llansó et al. 2005a) for details. The 2005 report can be found on the Maryland benthic monitoring program website (www.baybenthos.versar.com). The salient points of these patterns are the effect of mixed sources of stress, including contamination, eutrophication, and low dissolved oxygen stress, in the Patuxent River and Maryland's upper western tributaries; widespread hypoxia effects in the lower Potomac River; high sediment loads and excess nutrient inputs associated with excess abundance of organisms in Maryland's eastern tributaries; and anoxia in the deeper portions of the Maryland mainstem associated with a dead zone.

Post-stratification and the random nature of the sampling sites have allowed for inferences at small spatial scales and for reporting overall condition and identification of impaired waters (305b report) under the Clean Water Act (Llansó et al. 2005b). An extensive database has also allowed for the characterization of benthic resources in Chesapeake Bay using GIS methods. We used an inverse distance weighted interpolation algorithm to classify benthic communities into condition categories according to the type of hydrological year. Years with overall low (1999, 2002, and 2004) and high (1996, 2003, 2005) spring flows were combined, respectively, to map benthic community condition bay-wide (Figure 4-1). Inspection of the maps reveals differences between dry and wet years that are more pronounced in the tributaries. Wet years show an increase in the extent and intensity of degradation in the lower portion of the major tributaries (Patuxent, Potomac, Rappahannock, and York rivers), except for the James River. The

Maryland upper western tributaries also show overall increased degradation in wet years, with benthic community condition more often classified as severely degraded than in dry years. In the mainstem of the Bay, an increase in degraded area at the mouth of the Rappahannock River is apparent in wet years, but otherwise no clear differences are observed. Regions of the Maryland mainstem deeper than 12 m have been blocked off to indicate that these areas are not sampled because they are subjected to persistent anoxia and are considered to be azoic.

In another GIS application, we mapped the extent of habitat of bivalves that are important food items for diving ducks in Chesapeake Bay (Figure 4-2). Diving ducks winter in the Bay in large numbers and feed primarily on abundant infaunal and epifaunal bivalve species. In a joint study with the US Fish and Wildlife Service, Chesapeake Bay office, we used data from a mid-winter diving duck aerial survey conducted in the Chesapeake Bay between December 1992 and March 1993. Scoters, long-tailed duck, bufflehead, and common goldeneye were selected for this study. Long-term monitoring data were mapped to determine the habitat range of four bivalve species (*Gemma gemma*, *Macoma balthica*, *Mulinia lateralis*, and *Rangia cuneata*) and regions of high and low biomass (Figure 4-2). These four bivalve species are considered predominant prey items in the diet of diving ducks in Chesapeake Bay according to recent dietary analyses (Matthew C. Perry, Patuxent Wildlife Research Center, unpublished data). The hooked mussel (*Ischadium recurvum*) is also a major food item in the diet of scoters and goldeneyes. We do not have good data for hooked mussel because this species is usually associated with hard substrate and oyster reefs, which are not sampled by the benthic monitoring program. Therefore, we used data from oyster bottom surveys conducted in Maryland and Virginia in the mid 1980's to map areas that are presumably important hook mussel habitats.

We found significant associations between duck abundance and bivalve resources in some regions of the Chesapeake Bay. Figure 4-3 shows the expected distribution of ducks ("exp" column) if they occurred in proportion to the bottom area occupied by three benthic habitats: bivalves, oyster reefs, and other, estimated by interpolation. The observed distribution of ducks is then compared to the expected distribution. Goldeneye and long-tailed duck were over oyster habitat in greater numbers than expected in the Chester River, Choptank River, Potomac River, Eastern Bay, western portion of the mid Maryland mainstem, Tangier Sound, and the Maryland mainstem. All four duck species were usually associated with bivalve habitat in greater numbers than expected in regions were bivalve biomass is highest, such as the upper Bay (except for long-tailed duck), Eastern Bay (except for goldeneye), Choptank River (except for scoters), and the western portion of the mid Maryland mainstem. Several regions in Chesapeake Bay are subjected to hypoxia and may represent loss of potential duck feeding habitat. Therefore, the mapping and tracking of benthic resources in Chesapeake Bay gains importance as regions affected by hypoxia and pollution expand or contract as a result of changes in nutrient inputs, management actions, year-to-year variability in rainfall, and climate change.

In conclusion, bay-wide estimates of degradation were considerably higher in 2005 than in 2004. Some Chesapeake Bay regions exhibited the highest percent degraded area of the monitoring time series. The effects of above average spring flows were also detected at trend stations. Benthic community degradation continued to be large in the Chesapeake Bay. Much of the problem is excess organic matter from phytoplankton blooms and hypoxia. Despite substantial restoration efforts, we haven't seen significant changes in benthic community condition that would indicate widespread improvements in abundance, diversity, or biomass of organisms. Many of these organisms are the base for fisheries species, and as shown in a related study, they may constitute an important food resource for wintering sea ducks. It will probably take sustained management efforts over an extended period of time to bring back a more balanced community of benthic organisms and see significant bay-wide improvements in benthic condition.

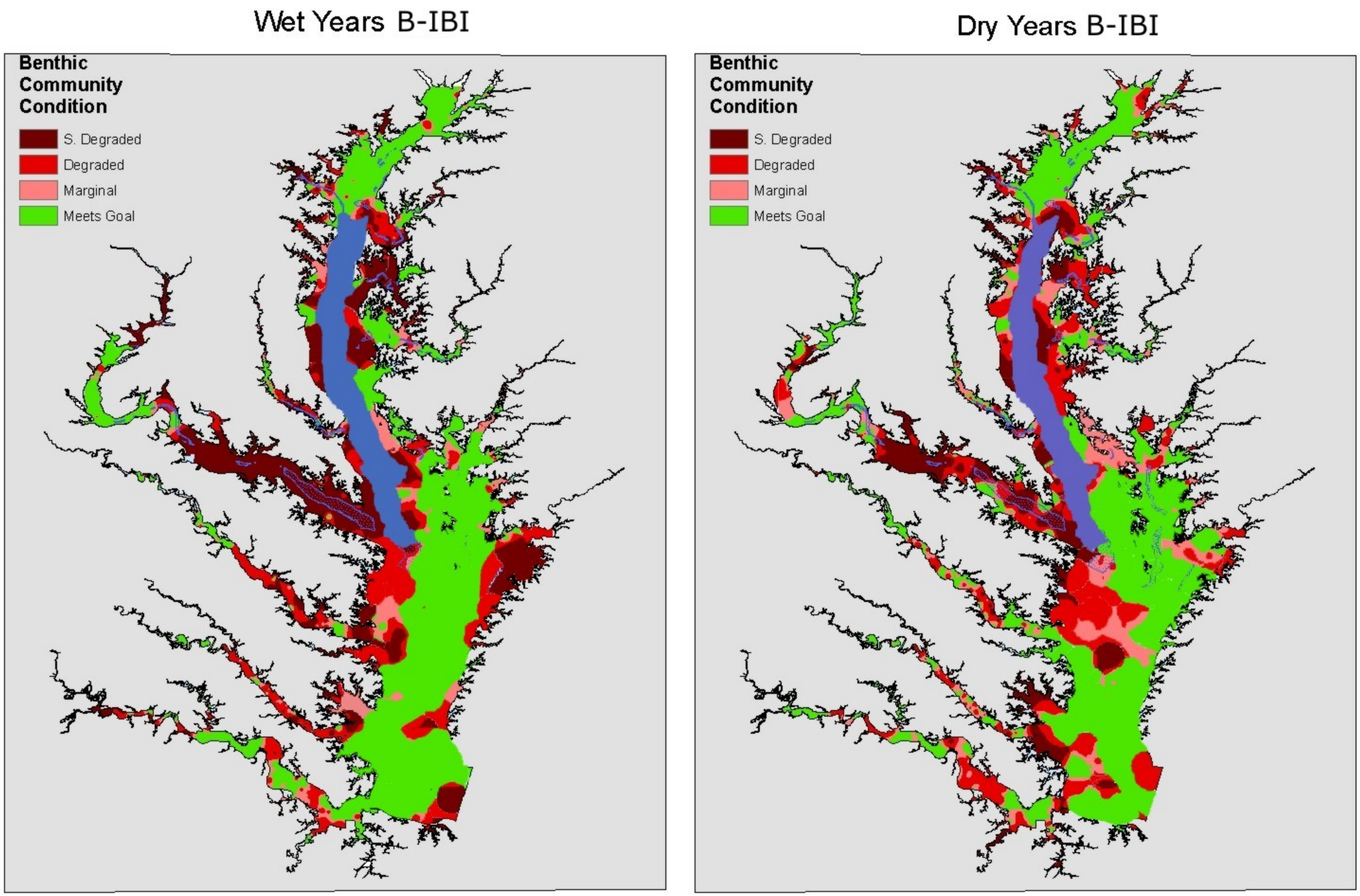

Figure 4-1. Benthic community condition in wet versus dry years.

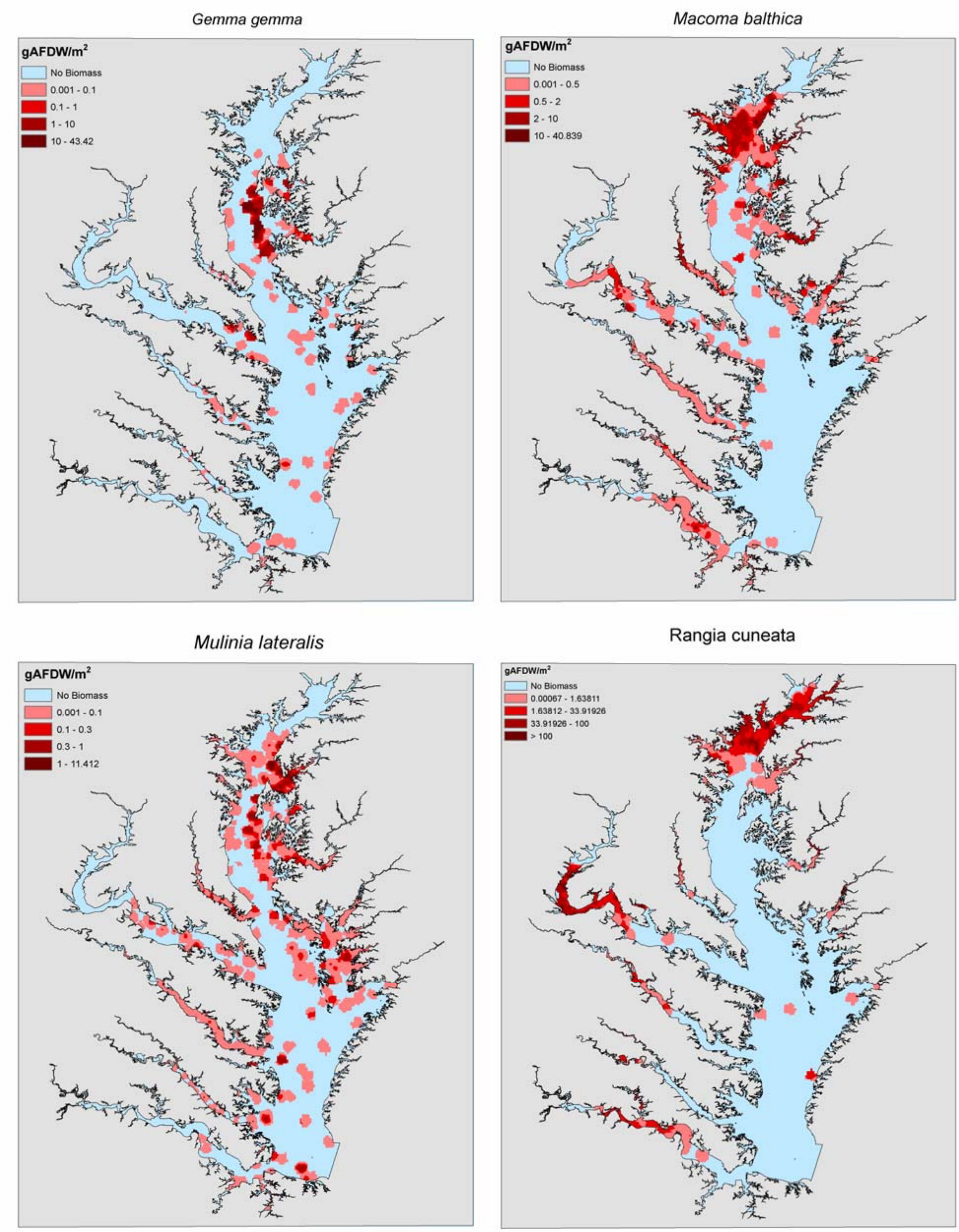

Figure 4-2. Habitat range of four species of bivalves.

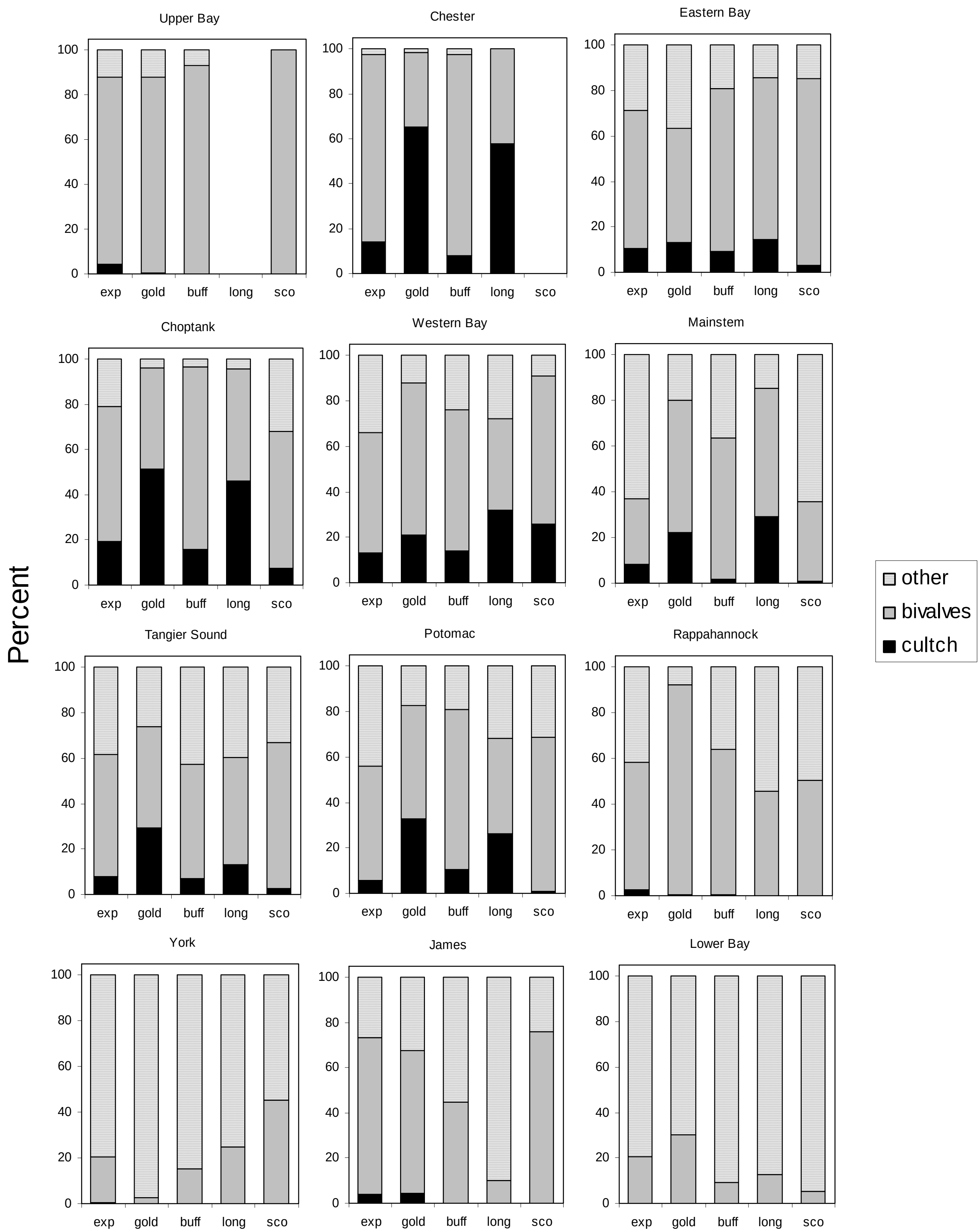

Figure 4-3. Proportions of four species of diving ducks over benthic habitats; exp = expected proportion based on area.

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APPENDIX A

FIXED SITE COMMUNITY ATTRIBUTE 1985-2005 TREND ANALYSIS RESULTS

Appendix Table A-1. Summer trends in benthic community attributes at mesohaline stations 1985-2005. Shown is the median slope of the trend. Monotonic trends were identified using the van Belle and Hughes (1984) procedure. Shaded cells indicate increasing degradation; unshaded cells indicate improving conditions; (a): trends based on 1989-2005 data; (b): trends based on 1995-2005 data; (c): attribute trend based on 1990-2005 data; (d): attributes are used in B-IBI calculations when species specific biomass is unavailable; (e): attribute and trend are not part of the reported B-IBI. Probability values shown in Table 3-2.

Station	B-IBI	Abundance	Biomass	Shannon Diversity	Indicative Abundance	Sensitive Abundance	Indicative Biomass (c)	Sensitive Biomass (c)	Abundance Carnivore/ Omnivores
Potomac River									
43	0.00	-69.67	-0.88	-0.00	0.30	-0.35 (d)	0.00 (e)	-0.13	-0.12 (e)
44	0.00	-34.68	-0.06	0.02	-0.40	0.00 (d)	0.00 (e)	-0.06	0.60 (e)
47	0.00	-41.33	-0.22	0.01	0.29	-0.91 (d)	0.01 (e)	-0.87	-0.36 (e)
51	0.03	0.00	-0.14	0.02	-0.79	0.42	0.18 (e)	-0.91 (e)	0.43
52	0.00	-5.68	-0.00	-0.00	0.00 (d)	0.00 (d)	0.00	0.00	-0.00
Patuxent River									
71	0.00	-51.65	-0.07	-0.01	-2.94 (d)	-0.14 (d)	-2.74	0.00	1.11
74	0.00	127.11	-1.27	-0.02	0.27	-1.33 (d)	0.00 (e)	-0.23	-0.54 (e)
77	-0.06	30.33	-0.16	0.00	1.31	-0.47 (d)	-2.14 (e)	3.06	-0.61 (e)
Choptank River									
64	0.03	28.96	0.10	0.02	-0.56 (d)	0.66 (d)	0.01	-1.10	0.00
Maryland Mainstem									
01	0.00	-10.67	0.02	-0.01	-0.33	0.56	-0.07 (e)	0.05 (e)	0.24
06	0.00	32.00	0.01	0.01	0.00	0.22	0.23 (e)	-2.51 (e)	0.00
15	0.04	24.00	0.01	0.01	-1.05	0.32	-0.03 (e)	0.86 (e)	0.34
24	0.00	-39.44	-0.13	-0.04	-0.70 (d)	0.36 (d)	-0.01	0.00	1.06
26	0.02	1.04	-1.06	0.01	0.00	0.63 (d)	0.00 (e)	-0.03	0.45 (e)
Maryland Western Shore Tributaries									
22	-0.01	-30.30	-0.03	-0.04	1.86	0.00 (d)	0.52 (e)	0.00	-0.61 (e)
23	0.00	-91.11	-0.01	-0.01	-0.18	0.51 (d)	-0.04 (e)	0.32	0.57 (e)
201(a)	0.00	-29.46	-0.00	0.00	0.00	0.00 (d)	1.69 (e)	0.00	0.00 (e)
202(a)	0.00	-41.31	0.00	0.00	0.00	0.00 (d)	0.00 (e)	0.00	0.00 (e)
204(b)	-0.17	-68.41	-0.34	0.02	1.92 (d)	-0.38 (d)	0.11	-4.56	-0.75
Maryland Eastern Shore Tributaries									
62	-0.03	60.77	-0.05	-0.05	0.00	-0.33 (d)	0.01 (e)	-2.51	-0.31 (e)
68	0.00	32.27	0.52	0.00	0.12	1.20 (d)	-0.00 (e)	-0.02	0.34 (e)

Appendix Table A-2. Summer trends in benthic community attributes at oligohaline and tidal freshwater stations 1985-2005. Shown is the median slope of the trend. Monotonic trends were identified using the van Belle and Hughes (1984) procedure. Shaded cells indicate increasing degradation; unshaded cells indicate improving conditions; (a): trends based on 1989-2005 data; NA: attribute not calculated. Probability values shown in Table 3-3.

Station	B-IBI	Abundance	Tolerance Score	Freshwater Indicative Abundance	Oligohaline Indicative Abundance	Oligohaline Sensitive Abundance	Tanypodinae to Chironomidae Ratio	Abundance Deep Deposit Feeders	Abundance Carnivore/ Omnivores
Potomac River									
36	0.00	-17.78	0.01	0.75	NA	NA	NA	0.59	NA
40	0.00	-3.30	0.00	NA	-0.53	0.00	0.00	NA	0.49
Patuxent River									
79	0.00	134.10	0.00	-0.76	NA	NA	NA	-0.07	NA
Choptank River									
66	0.00	79.55	0.11	NA	0.61	0.00	1.01	NA	0.91
Maryland Western Shore Tributaries									
203(a)	0.00	-22.84	-0.03	NA	0.00	0.00	2.95	NA	1.33
Maryland Eastern Shore Tributaries									
29	0.01	-45.54	-0.06	NA	-1.53	0.14	0.00	NA	0.23

APPENDIX B

FIXED SITE B-IBI VALUES, SUMMER 2005

Appendix Table B-1. Fixed site B-IBI values, Summer 2005

Station	Sampling Date	Latitude (WGS84 Decimal Degrees)	Longitude (WGS84 Decimal Degrees)	B-IBI	Status
001	9/13/2005	38.41967	-76.41917	3.22	Meets Goal
006	9/13/2005	38.44203	-76.44422	2.22	Degraded
015	9/13/2005	38.71510	-76.51398	3.33	Meets Goal
022	8/31/2005	39.25388	-76.58815	1.27	Severely Degraded
023	8/31/2005	39.20855	-76.52420	1.53	Severely Degraded
024	9/1/2005	39.12137	-76.35598	2.67	Marginal
026	9/1/2005	39.27092	-76.28965	2.87	Marginal
029	9/23/2005	39.47948	-75.94497	2.89	Marginal
036	9/9/2005	38.76943	-77.03778	3.00	Meets Goal
040	9/27/2005	38.35725	-77.23097	3.06	Meets Goal
043	9/27/2005	38.38552	-76.99603	3.67	Meets Goal
044	9/27/2005	38.38552	-76.99603	2.47	Degraded
047	9/27/2005	38.36393	-76.98378	4.33	Meets Goal
051	9/29/2005	38.20547	-76.73825	1.89	Severely Degraded
052	8/29/2005	38.19223	-76.74875	1.00	Severely Degraded
062	9/20/2005	38.38420	-75.85080	3.00	Meets Goal
064	9/21/2005	38.59040	-76.06967	4.22	Meets Goal
066	9/19/2005	38.80130	-75.92225	2.89	Marginal
068	9/19/2005	39.12985	-76.07947	4.47	Meets Goal
071	9/2/2005	38.39510	-76.54905	1.89	Severely Degraded
074	9/7/2005	38.55073	-76.67773	2.60	Degraded
077	9/7/2005	38.60435	-76.67527	2.07	Degraded
079	9/7/2005	38.74965	-76.68967	3.00	Meets Goal
201	8/31/2005	39.23385	-76.49737	1.40	Severely Degraded
202	8/31/2005	39.21742	-76.56462	1.00	Severely Degraded
203	9/16/2005	39.27515	-76.44440	1.78	Severely Degraded
204	9/8/2005	39.00665	-76.50497	2.33	Degraded

APPENDIX C

RANDOM SITE B-IBI VALUES, SUMMER 2005

Appendix Table C-1. Random site B-IBI values, Summer 2005

Station	Sampling Date	Latitude (WGS84 Decimal Degrees)	Longitude (WGS84 Decimal Degrees)	B-IBI	Status
MET-12401	9/28/2005	38.111	-75.875	1.67	Severely Degraded
MET-12403	9/28/2005	38.13	-75.844	3.00	Meets Goal
MET-12404	9/20/2005	38.217	-75.85	2.33	Degraded
MET-12405	9/20/2005	38.226	-75.845	3.67	Meets Goal
MET-12406	9/20/2005	38.273	-75.92	3.67	Meets Goal
MET-12407	9/20/2005	38.488	-75.809	2.67	Marginal
MET-12409	9/21/2005	38.599	-75.992	3.80	Meets Goal
MET-12411	9/21/2005	38.611	-76.093	4.00	Meets Goal
MET-12412	9/19/2005	39.005	-76.212	3.00	Meets Goal
MET-12414	9/19/2005	39.02	-76.243	2.00	Severely Degraded
MET-12415	9/19/2005	39.047	-76.187	3.67	Meets Goal
MET-12416	9/19/2005	39.051	-76.199	3.00	Meets Goal
MET-12417	9/19/2005	39.107	-76.176	3.40	Meets Goal
MET-12418	9/19/2005	39.109	-76.139	4.60	Meets Goal
MET-12419	9/19/2005	39.154	-76.062	2.20	Degraded
MET-12420	9/19/2005	39.239	-75.99	2.67	Marginal
MET-12421	9/1/2005	39.367	-76.023	3.00	Meets Goal
MET-12422	9/23/2005	39.487	-75.955	1.67	Severely Degraded
MET-12423	9/23/2005	39.491	-75.941	3.00	Meets Goal
MET-12424	9/23/2005	39.507	-75.893	2.67	Marginal
MET-12425	9/23/2005	39.514	-75.879	2.67	Marginal
MET-12427	9/28/2005	38.069	-75.789	2.00	Severely Degraded
MET-12428	9/20/2005	38.382	-75.852	3.00	Meets Goal
MET-12429	9/20/2005	38.527	-75.752	2.60	Degraded
MET-12430	9/19/2005	39.067	-76.161	3.40	Meets Goal
MMS-12501	8/30/2005	37.917	-76.232	2.33	Degraded
MMS-12502	8/30/2005	37.976	-76.141	1.00	Severely Degraded
MMS-12503	9/28/2005	37.98	-75.982	3.00	Meets Goal
MMS-12504	8/30/2005	37.989	-76.271	1.00	Severely Degraded
MMS-12505	8/30/2005	38.027	-76.137	2.67	Marginal
MMS-12506	8/30/2005	38.043	-76.302	2.00	Severely Degraded
MMS-12507	8/30/2005	38.048	-76.102	3.67	Meets Goal
MMS-12508	8/30/2005	38.112	-76.289	1.00	Severely Degraded
MMS-12510	8/30/2005	38.191	-76.206	1.00	Severely Degraded
MMS-12511	8/30/2005	38.219	-76.073	3.67	Meets Goal
MMS-12512	8/29/2005	38.236	-76.35	2.33	Degraded
MMS-12513	8/30/2005	38.253	-76.134	2.33	Degraded
MMS-12514	8/30/2005	38.26	-76.338	1.00	Severely Degraded

Appendix Table C-1. (Continued)					
Station	Sampling Date	Latitude (WGS84 Decimal Degrees)	Longitude (WGS84 Decimal Degrees)	B-IBI	Status
MMS-12515	8/30/2005	38.274	-76.271	2.67	Marginal
MMS-12516	9/20/2005	38.338	-75.986	3.80	Meets Goal
MMS-12517	8/30/2005	38.353	-76.387	3.00	Meets Goal
MMS-12518	9/13/2005	38.505	-76.484	2.33	Degraded
MMS-12519	9/13/2005	38.621	-76.338	1.00	Severely Degraded
MMS-12520	9/21/2005	38.639	-76.199	3.00	Meets Goal
MMS-12521	9/21/2005	38.721	-76.128	2.33	Degraded
MMS-12523	9/13/2005	38.838	-76.478	2.33	Degraded
MMS-12524	9/21/2005	38.888	-76.111	3.00	Meets Goal
MMS-12525	9/28/2005	38.914	-76.291	2.00	Severely Degraded
MMS-12526	9/13/2005	38.745	-76.527	4.33	Meets Goal
MMS-12527	9/13/2005	38.505	-76.462	1.00	Severely Degraded
MWT-12301	9/8/2005	38.859	-76.508	4.00	Meets Goal
MWT-12302	9/8/2005	38.859	-76.532	2.33	Degraded
MWT-12303	9/8/2005	38.866	-76.5	4.33	Meets Goal
MWT-12304	9/8/2005	38.989	-76.485	3.33	Meets Goal
MWT-12305	9/8/2005	39.005	-76.504	2.33	Degraded
MWT-12306	9/8/2005	39.032	-76.569	1.80	Severely Degraded
MWT-12307	9/8/2005	39.036	-76.563	3.00	Meets Goal
MWT-12308	9/8/2005	39.068	-76.468	1.80	Severely Degraded
MWT-12310	8/31/2005	39.163	-76.467	4.20	Meets Goal
MWT-12311	8/31/2005	39.174	-76.501	1.80	Severely Degraded
MWT-12312	8/31/2005	39.177	-76.487	1.00	Severely Degraded
MWT-12313	8/31/2005	39.182	-76.452	1.00	Severely Degraded
MWT-12314	8/31/2005	39.19	-76.45	2.60	Degraded
MWT-12315	8/31/2005	39.207	-76.459	3.80	Meets Goal
MWT-12316	8/31/2005	39.209	-76.514	1.80	Severely Degraded
MWT-12317	8/31/2005	39.209	-76.522	1.00	Severely Degraded
MWT-12318	8/31/2005	39.225	-76.506	3.80	Meets Goal
MWT-12319	8/31/2005	39.235	-76.496	3.00	Meets Goal
MWT-12320	9/16/2005	39.244	-76.421	1.80	Severely Degraded
MWT-12321	8/31/2005	39.247	-76.492	1.40	Severely Degraded
MWT-12322	8/31/2005	39.249	-76.489	1.00	Severely Degraded
MWT-12323	9/16/2005	39.251	-76.604	3.40	Meets Goal
MWT-12324	8/31/2005	39.252	-76.566	1.00	Severely Degraded
MWT-12325	8/31/2005	39.256	-76.567	2.20	Degraded
MWT-12326	9/16/2005	39.271	-76.444	2.00	Severely Degraded
PMR-12101	8/29/2005	37.95	-76.339	2.33	Degraded

Appendix Table C-1. (Continued)					
Station	Sampling Date	Latitude (WGS84 Decimal Degrees)	Longitude (WGS84 Decimal Degrees)	B-IBI	Status
PMR-12102	8/29/2005	37.958	-76.346	2.00	Severely Degraded
PMR-12103	8/29/2005	37.988	-76.335	1.00	Severely Degraded
PMR-12104	8/29/2005	38.023	-76.413	1.00	Severely Degraded
PMR-12105	8/29/2005	38.037	-76.476	1.00	Severely Degraded
PMR-12106	8/29/2005	38.048	-76.341	2.33	Degraded
PMR-12107	8/29/2005	38.066	-76.482	1.00	Severely Degraded
PMR-12108	8/29/2005	38.099	-76.519	1.00	Severely Degraded
PMR-12109	8/29/2005	38.101	-76.494	1.00	Severely Degraded
PMR-12110	8/29/2005	38.204	-76.61	1.00	Severely Degraded
PMR-12111	9/29/2005	38.212	-76.736	2.00	Severely Degraded
PMR-12112	8/29/2005	38.213	-76.627	1.00	Severely Degraded
PMR-12113	9/29/2005	38.219	-76.866	1.00	Severely Degraded
PMR-12114	9/29/2005	38.228	-76.855	1.40	Severely Degraded
PMR-12116	8/29/2005	38.251	-76.662	1.00	Severely Degraded
PMR-12117	9/29/2005	38.283	-76.806	2.00	Severely Degraded
PMR-12118	9/30/2005	38.305	-76.964	1.40	Severely Degraded
PMR-12119	9/29/2005	38.336	-76.84	2.20	Degraded
PMR-12120	9/30/2005	38.341	-77.0	3.80	Meets Goal
PMR-12121	9/27/2005	38.363	-77.171	3.40	Meets Goal
PMR-12122	9/27/2005	38.367	-77.276	2.33	Degraded
PMR-12123	9/27/2005	38.381	-77.141	2.60	Degraded
PMR-12124	9/27/2005	38.463	-77.039	1.00	Severely Degraded
PMR-12125	9/9/2005	38.54	-77.263	2.00	Severely Degraded
PMR-12126	9/9/2005	38.521	-77.273	3.00	Meets Goal
PXR-12201	9/2/2005	38.294	-76.451	2.33	Degraded
PXR-12202	9/2/2005	38.295	-76.449	2.00	Severely Degraded
PXR-12203	9/2/2005	38.302	-76.425	3.33	Meets Goal
PXR-12204	9/2/2005	38.302	-76.451	2.00	Severely Degraded
PXR-12205	9/2/2005	38.307	-76.457	1.00	Severely Degraded
PXR-12206	9/2/2005	38.312	-76.469	3.33	Meets Goal
PXR-12208	9/2/2005	38.378	-76.518	3.00	Meets Goal
PXR-12209	9/2/2005	38.384	-76.498	2.00	Severely Degraded
PXR-12210	9/2/2005	38.387	-76.526	2.33	Degraded
PXR-12211	9/2/2005	38.393	-76.498	1.00	Severely Degraded
PXR-12212	9/2/2005	38.404	-76.572	1.00	Severely Degraded
PXR-12213	9/2/2005	38.413	-76.588	1.00	Severely Degraded
PXR-12214	9/2/2005	38.436	-76.612	2.33	Degraded
PXR-12215	9/2/2005	38.461	-76.628	2.00	Severely Degraded

Appendix Table C-1. (Continued)

Station	Sampling Date	Latitude (WGS84 Decimal Degrees)	Longitude (WGS84 Decimal Degrees)	B-IBI	Status
PXR-12216	9/2/2005	38.461	-76.658	3.40	Meets Goal
PXR-12218	9/2/2005	38.477	-76.661	3.33	Meets Goal
PXR-12219	9/2/2005	38.481	-76.653	2.67	Marginal
PXR-12220	9/2/2005	38.485	-76.655	2.33	Degraded
PXR-12221	9/2/2005	38.487	-76.667	2.60	Degraded
PXR-12222	9/7/2005	38.523	-76.665	3.80	Meets Goal
PXR-12223	9/7/2005	38.591	-76.672	2.60	Degraded
PXR-12224	9/7/2005	38.729	-76.696	1.80	Severely Degraded
PXR-12225	9/7/2005	38.737	-76.688	3.67	Meets Goal
PXR-12226	9/2/2005	38.323	-76.434	2.33	Degraded
PXR-12227	9/2/2005	38.429	-76.602	2.00	Severely Degraded
UPB-12602	9/1/2005	39.031	-76.361	1.00	Severely Degraded
UPB-12603	9/1/2005	39.055	-76.36	3.67	Meets Goal
UPB-12604	9/1/2005	39.1	-76.39	3.80	Meets Goal
UPB-12605	9/1/2005	39.108	-76.366	3.40	Meets Goal
UPB-12607	9/1/2005	39.127	-76.367	4.60	Meets Goal
UPB-12608	9/1/2005	39.124	-76.291	3.00	Meets Goal
UPB-12609	9/1/2005	39.143	-76.403	3.40	Meets Goal
UPB-12610	9/1/2005	39.18	-76.368	3.80	Meets Goal
UPB-12611	9/1/2005	39.187	-76.396	5.00	Meets Goal
UPB-12612	9/1/2005	39.191	-76.304	3.80	Meets Goal
UPB-12613	9/1/2005	39.197	-76.334	4.20	Meets Goal
UPB-12614	9/1/2005	39.211	-76.348	4.20	Meets Goal
UPB-12615	9/1/2005	39.23	-76.242	3.80	Meets Goal
UPB-12616	9/1/2005	39.231	-76.254	4.20	Meets Goal
UPB-12617	9/1/2005	39.246	-76.245	3.40	Meets Goal
UPB-12618	9/1/2005	39.247	-76.296	3.40	Meets Goal
UPB-12619	9/1/2005	39.254	-76.249	3.80	Meets Goal
UPB-12620	9/1/2005	39.272	-76.346	3.40	Meets Goal
UPB-12622	9/1/2005	39.356	-76.151	3.40	Meets Goal
UPB-12623	9/1/2005	39.406	-76.035	3.00	Meets Goal
UPB-12624	9/1/2005	39.437	-76.059	3.00	Meets Goal
UPB-12625	9/1/2005	39.457	-76.015	3.33	Meets Goal
UPB-12626	9/1/2005	39.119	-76.263	3.40	Meets Goal
UPB-12628	9/1/2005	39.193	-76.349	4.60	Meets Goal
UPB-12629	9/1/2005	39.481	-76.076	5.00	Meets Goal